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An Educational Game about Math and Magic

Dissertação para obtenção do Grau de Mestre em
Engenharia Informática

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UNIVERSIDADE NOVA DE LISBOA

Dezembro, 2018

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À minha família e amigos.

Acknowledgements

I would like to thank my dissertation advisors, Prof.ª Teresa Romão and Prof. Nuno Correia, for the time and support they offered during these months, and their dedication to helping me make my dissertation the best it could be.

I would also like to thank Miguel Pedro from Watizeet for believing in my work and my ideas and supporting me from the beginning, providing me with the means to do the dissertation I hoped for.

I dedicate this dissertation to my family and my friends, who support me in many and various ways throughout my life and are there for me when I need them most, and specially my cousin, David Pinto, who dedicated his time to help me by creating all the graphics in the game.

Finally, a very big thank you to Prof.ª Fernanda Pedro, the Agrupamento de Escolas Emídio Navarro and all the parents and students of the classes 6º4 and 6º7 of 2017/18, 6º1 and 6º2 of 2018/2019 for providing the means for me to test my dissertation and gather the feedback needed to improve it.

Abstract

Every year, technology keeps expanding and progressing, which leads to new ideas and new uses of technology in all kinds of areas, and education is no exception. The concept of using games as a mean of education is old, however, due to the recent advances of technology and the creation of videogames, the concept became more popular. With benefits ranging from a deeper understanding of the subject taught in the game, to various other skills obtained passively from playing games, educational games are an idea that should be focused on and developed further.

Students spend a very big portion of their free time interacting with their phones. Mobile games are a great way to pass the time with little effort and are enjoyable for being simple and fun. However, most of the mobile games have no real educational purpose. Meanwhile, most students struggle with some school subjects and end up losing the motivation to study, which leads to them failing classes or losing important knowledge. Therefore, we decided to create a game that would appeal to them, while also helping them obtain or solidify their math knowledge.

We created the game in a way that takes the focus from the educational aspects, using a unique story, characters and challenges that keep the player entertained. With math questions being answered in different ways like leaning the phone one way or another to make the character reach the right answer, drawing the answer to a question on the screen with a finger like a magic spell, or even having a math duel with an evil wizard, the player can have fun while answering them. To help the player learn from their mistakes the game also offers, after they answer a question, a small explanation of what the right answer was and why.

The game was found to have a positive effect on the students, creating interest and improving their knowledge, and we were able to create a few guidelines to help increase the success of future educational games.

Keywords: Mobile game, Educational game, Multiple-choice questions, Interaction Mechanisms, Shape Recognition, Accelerometer, Unity.

Resumo

Todos os anos a tecnologia continua a expandir-se e a progredir, o que leva a novas ideias e novos usos desta em variadas áreas, e a educação não é uma exceção. O conceito de usar jogos como um meio para a educação é antigo, no entanto, devido a recentes avanços na tecnologia e à criação de videojogos, o conceito tornou-se mais popular. Com benefícios desde uma mais profunda compreensão da matéria ensinada no jogo, até várias outras capacidades obtidas passivamente ao jogar jogos, os jogos educacionais são uma ideia que devia ser mais focada e desenvolvida.

Alunos passam uma grande parte do seu tempo livre no telemóvel. Jogos móveis são uma boa maneira de passar o tempo com pouco esforço e são agradáveis por serem simples e divertidos. No entanto, a maior parte dos jogos móveis não têm um propósito educacional, servem apenas para entreter o utilizador, e esse tempo acaba por ser desperdiçado. Ao mesmo tempo, a maior parte dos estudantes tem dificuldades em alguma das matérias escolares e acaba por ficar desmotivado para estudar, o que faz com que chumbem às disciplinas ou percam bases importantes da sua educação. Sendo assim, decidimos criar um jogo que os cativasse, enquanto os ajuda a obter ou solidificar o seu conhecimento em matemática.

Criámos o jogo de forma a que o foco seja afastado do aspeto educacional, usando uma história única, personagens e desafios que mantém o jogador entretido. Com perguntas de matemática que são respondidas de formas variadas, como inclinar o telemóvel para fazer a personagem chegar à resposta certa, desenhar a resposta no ecrã com o dedo como um feitiço, ou mesmo ter um duelo com o matemágico, o jogador pode divertir-se enquanto responde. Para ajudar o jogador a aprender com os seus erros o jogo também oferece, após cada questão respondida, uma pequena explicação da resposta correta.

O jogo teve um efeito positivo nos estudantes, criando interesse e melhorando o seu conhecimento, e conseguimos criar algumas diretrizes para ajudar ao sucesso de futuros jogos educativos.

Palavras-chave: Jogo móvel, Jogo educacional, Perguntas de escolha múltipla, Mecanismos de Interação, Reconhecimento de formas, Acelerómetro, Unity.

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Introduction

1.1. Motivation

Every year, technology as a whole keeps expanding and progressing, which leads to new ideas and new uses of technology in all kinds of areas, and education is no exception. The concept of using games as a mean of education is old, dating back to the middle ages when men used the game of chess to learn war tactics. However, due to the recent advances of technology and the creation of video-games, the concept became more popular.

The first educational video-game appeared in 1971 and was called Oregon Trail[1]. This game taught about the difficulties of the western expansion of the United States and was used for several generations in American history classes. Since then, and with the advances of technology, the area just kept expanding.

Some popular educational videogames include SimCity Edu[2] (an educational version of the popular game SimCity where you play the role of mayor, addressing environmental impact while balancing the employment needs and the happiness of the residents), Scribblenauts[3] (where you have the power to summon any object you can think off, and use that to solve the problems you are faced with), Professor Layton (where you are required to solve different kinds of puzzles

[1] https://en.wikipedia.org/wiki/The_Oregon_Trail_(video_game)/
[2] https://www.glasslabgames.org/games/SC/
[3] https://www.scribblenauts.com/

connected through a strong narrative context) and Little Big Planet[4] (where you have the freedom to create your own game stages and rules with the building tools offered).

This type of game, like any other game, can be developed in all sorts of platforms. From the examples above, SimCity Edu can be played on PC or Mac, while Professor Layton can be played on Nintendo consoles, Scribblenauts can be played on both and Little Big Planet can only be played on Playstation. However, you can find educational videogames in almost any gaming platform, be it a console, a computer, a phone or a tablet. You can also find educational videogames about the most varied subjects, from math (e.g. What is Geometry), to music (e.g. Piano Wizard[5]), to history (e.g. The Oregon Trail), or even teamwork skills (e.g. 9Mind7[6]).

With benefits ranging from a deeper understanding of the subject taught in the game, to various other skills obtained passively from playing games, educational games are an idea that should be focused on and developed further.

1.2. Context

This dissertation was developed in the context of the master's degree of the computer engineering course at the Faculdade de Ciências e Tecnologias da Universidade de Lisboa in collaboration with the start-up company Watizeet[7], a company focused on creating mobile educational games and creator of the game "What Is Geometry?"[8], an augmented reality mobile game focused on teaching geometry to children.

1.3. Problem description

Students spend a very big portion of their free time interacting with their phones. Mobile games are a great way to pass the time with little effort and are enjoyable for being simple and fun. However, most of the mobile games have no real educational purpose. Meanwhile, most students struggle with some school subjects and end up losing the motivation to study, which leads to them failing classes or losing important knowledge. Therefore, we decided to create a game that would appeal to them, while also helping them obtain or solidify their math knowledge.

[4] https://www.playstation.com/en-gb/games/littlebigplanet-ps3/
[5] https://www.pianowizardacademy.com/
[6] https://play.google.com/store/apps/details?id=com.ninemindseven.quizlearning/
[7] http://www.watizeet.com/
[8] https://play.google.com/store/apps/details?id=com.watizeet.geometry/

1.4. Solution

We created a mobile game to be played by 5th and 6th grade students during their free time, to solidify the knowledge they obtain at school while playing without feeling like they are actually studying. In this game, named "A Mathematical Situation", the player helps a young magician on their quest to stop the evil wizard, who stole all the math in the world for himself. The wizard is hiding on his magic mansion and so the player will have to walk through the corridors and rooms of the mansion to find him. Since the mansion is full of magic, the doors can lead anywhere, and there is no clear path to the evil wizard. In every corridor, the player will encounter three different doors, each one leading to a different room. The player should then choose one of the doors and will end up inside the corresponding room.

Moving through the different rooms, the player will find themselves in different situations, requiring different actions. During the game they will sometimes have to answer a math question, while other times they will be able to play a minigame or have to decide on the difficult choice of opening a mysterious chest or not. The mystery of not knowing what type of room they will find themselves in next keeps the player interested in the game, while the variety of rooms, questions and ways to answer them keeps the game from becoming repetitive and boring.

The player will also be collecting keys as they play, giving the game a sense of progression, even though they are walking into random rooms. When they obtain seven keys, they will finally find and face the evil wizard in a math duel, answering a series of questions until one of them runs out of lives and the game ends.

Our goal is to keep the player motivated by shifting the focus from the math questions and onto the fun and challenging aspect of the game. The player will still be answering questions, but in fun and different ways, and with lots of other fun things happening in between. We also provide a small explanation of each answer, so that the player will not just memorize the answer, but actually understand the why and how of it.

1.5. Main expected contributions

The main contribution of this dissertation is the creation of a mobile educational game in the Unity game engine that allows 5th and 6th grade students to occupy their free time doing something they enjoy and benefits them educationally. The purpose of this game is to increase the knowledge of the students on the math

subjects learned during 5th and 6th grade and help them retain the knowledge from previous school years. A prototype game was also tested with the target audience in order to gather feedback.

This dissertation also contributes as a study of how to effectively mask educational features in a game using tools like storytelling and different forms of interaction.

A poster about this dissertation was also accepted, published and presented at ICGI 2018 (Lemos et al., 2018).

2

State of the Art

2.1. Videogames on education

In recent years there has been a big focus on using videogames as a learning method, mostly because of their ability to captivate attention and hold it for lengthy periods of time.

As reviewed by Dondlinger (2007), educational games use interactivity to transmit non-trivial knowledge, by requiring players to strategize, test hypothesis, or solve problems. These games usually include a system of rewards or goals to motivate the player, a context to the activities, and learning content relevant to that context. According to Lee et al. (2004), a handheld math facts game for second graders made those who played it solve three times more problems in the same time as those using paper worksheets.

2.1.1. Good videogame design

While not everyone agrees on the factors that motivate someone to play these games, it is true that motivating players to play the game is a very important part of an educational game. Amory et al. (1999) made a study where they learned that students tend to be more motivated to play games that challenge them to utilize higher order thinking skills, like adventure or strategy games.

Another important part of a videogame is the narrative context. Waraich (2004) analysed the role of both narrative context and game goals as features for motivating and conceptualizing learning in a 2-D interactive learning environment (ILE) and concluded that "For any learning task to be meaningful to the

learner they must have both a sufficient context for the learning and motivation to perform the tasks that will help them to learn. We believe that game-based learning environments that incorporate a strong narrative can meet these requirements if the learning tasks are appropriately designed and tightly coupled with the narrative" (p. 98). Basically, for an educational videogame to motivate the students to play, it needs not only a strong story that grabs the player's attention, but also learning tasks that make sense with the story. If you are playing, for example, a racing car game, and during the race you are asked to solve, let's say, a math problem, it will be a strange fit.

According to Fisch's research (2005), seductive details on the videogame also work poorly. In those cases, students will remember the appealing elements of the game, but forget the educational content it is supposed to teach. For an effective learning, the educational content must be placed inside the game in the form of engaging gameplay.

Finally, a good videogame needs a good system of objectives, goals and rules. This system helps keeping the player engaged in the game.

Swartout and van Lent (2003) found out that giving the player goals of different levels to achieve helps them being more engaged. They mention there are "three levels of goals: short-term (collect the magic keys), lasting, perhaps, seconds; medium-term (open the enchanted safe), lasting minutes; and finally, long-term (save the world), lasting the length of the game" and that the "interplay of these levels, with the support of the environment, is crafted to draw players into the storyline of the game" (p.34).

2.1.2. Learning outcomes

While it is true that an educational game teaches the player about a specific subject, like a book would do, it is also true that the players get a whole other set of important skills from it. 21st century skills like "attention, spatial concentration, problem-solving, decision-making, collaborative work, creativity, and, of course, ICT skills" as mentioned by Aguilera and Mendiz (2003), but also, as Dondlinger (2007) refers, skills like deduction, hypothesis testing, understanding complex concepts. abstract thinking, visual and spatial processing are increased in videogame players (Dondlinger, 2007).

2.1.3. Mobile videogames in education

As Koutromanos and Avraamidou (2014) mention, mobile games recently started being used in support of student learning, both in formal and informal settings.

These games can be defined as "embedded, downloaded, or networked games conducted in handled devices" (Jeong and Kim, 2009). The rapid growth of these mobile games is mostly due to the mobility, accessibility, networkability and simplicity of the handled devices they are played on. Since they can be played anytime and anywhere, as Jeong and Kim (2009) said, they do not necessarily need to be used in the classroom (Seppala and Alamaki, 2003) and have the potential to improve efficiency and effectiveness in teaching and learning (Dubendorf, 2003).

Koutromanos and Avraamidou (2014) also summarized the advantages of mobile games in education after reviewing various studies. They found out that these games not only support student learning and engagement, but also offer various unique and contemporary learning opportunities. They offer opportunities for hands-on activities, role-playing, teaching within informal learning environments, understanding the relationship between science and technology, and developing various skills as, for example, the capacity of constructing arguments or debating. In addition to that, mobile games also often promote collaboration and interaction between players. So, these games open a door for new opportunities to enhance motivation, interest, interaction and engagement in education.

2.1.4. Motivation is the key

Huizenga et al. (2009) mentioned that research on mobile game-based learning usually focuses on the motivational effects of the methods used. This is because the purpose of these games is to help students achieve a state of motivated learner. These learners can be easily described: "They are enthusiastic, focused, and engaged. They are interested in and enjoy what they are doing, they try hard, and they persist over time. Their behavior is self-determined, driven by their own volition rather than external forces." (Garris et al., 2006).

The work of Malone and Lepper (1987) serves as base for many of these studies, as they proposed that the effectiveness of a student's learning of a subject is related to their level of intrinsic motivation, which is defined by something a person does for their own sake, rather than in order to receive some external reward or avoid external punishment. They believed there are seven factors that promote intrinsic motivation. These are challenge, curiosity, control, fantasy, competition, cooperation and recognition, and according to authors like Prensky (2001), Garris et al. (2006) and Egenfeldt-Nielsen (2006), many of these factors are triggered by games. In conclusion, one of the big benefits of educational games is that they utilize the factors that promote intrinsic motivation to help students become motivated learners in order to increase their learning effectiveness.

2.1.5. Examples of educational videogames

Educational videogames cover a wide range of subjects and platforms. In this sub-chapter can be found some examples of already created educational videogames and a brief explanation of each one.

What is Geometry

What is Geometry is a mobile educational game previously developed by Watizeet with the goal of teaching children about geometric shapes. In the game you are given a question or statement and your objective is to find the geometric shape that applies to the situation. For example, if the game asks you to find a shape with four sides of equal lengths, you should answer by detecting a square. The detection is made via the phone's camera, pointing at objects in the real world with the corresponding shape. The game was created using Android Studio and the augmented reality technology was based on the OpenCV library and developed by Ferreira (2014) in his dissertation. Figures 2.1, 2.2 and 2.3 below show the question, detection and victory screens of the game, respectively. ("What is Geometry", 2018)

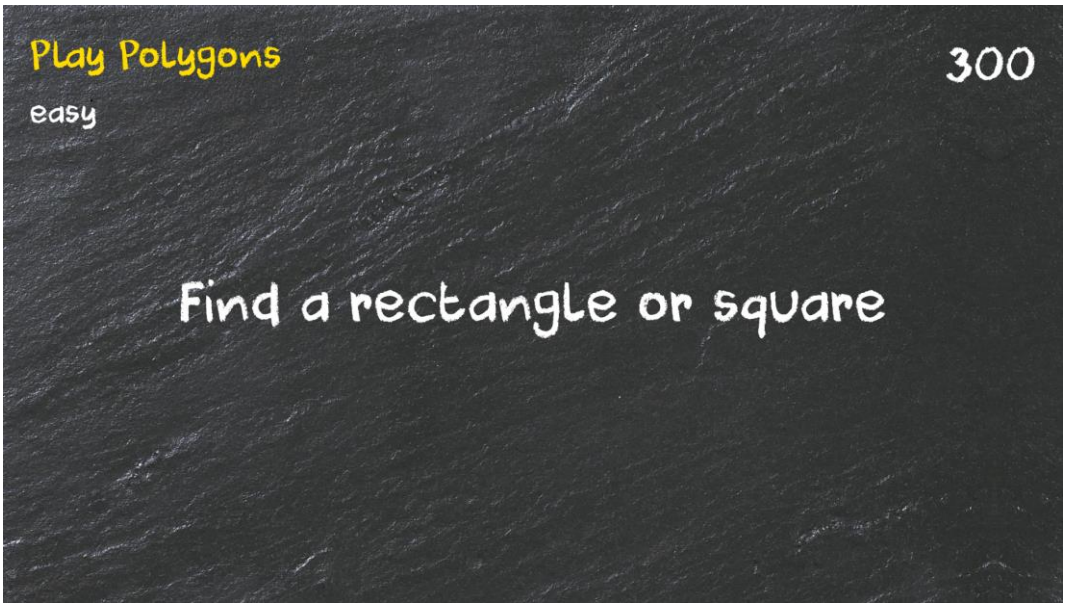

Figure 2.1: What is Geometry – Question Screen

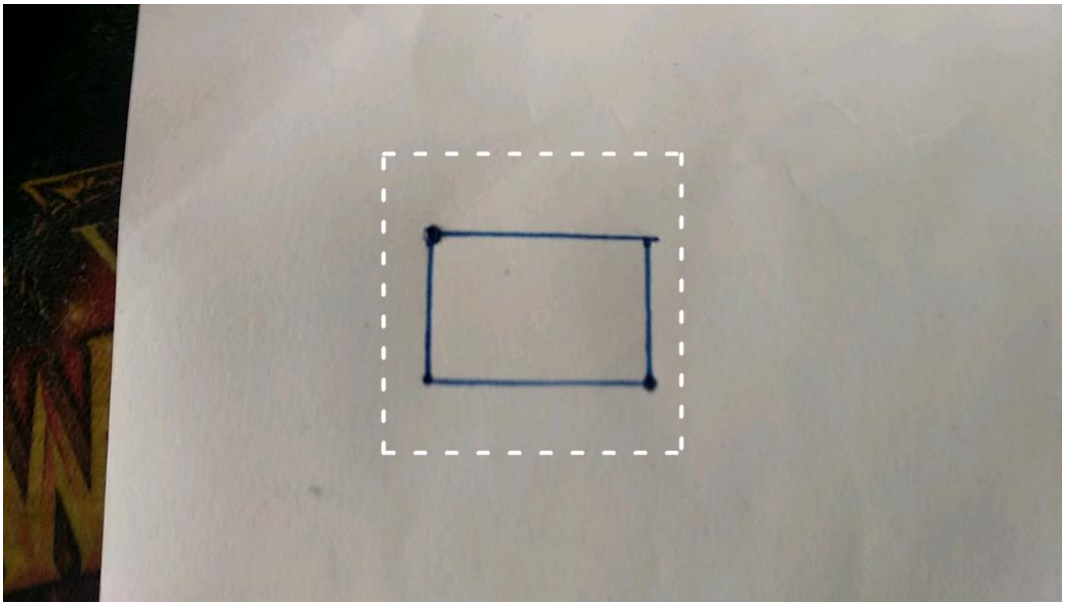

Figure 2.2: What is Geometry – Detection Screen

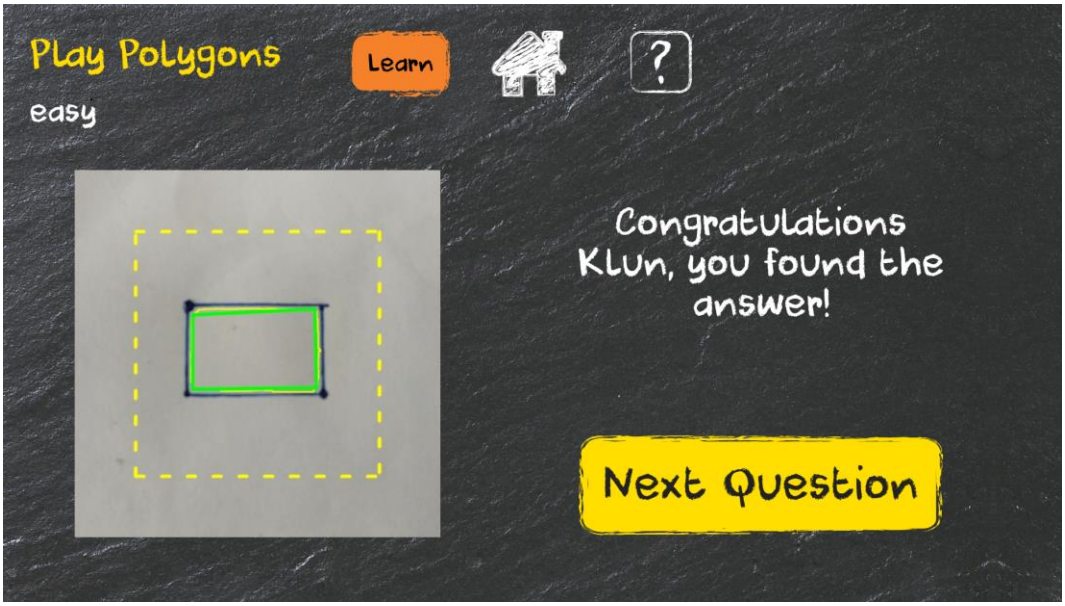

Figure 2.3: What is Geometry – Victory Screen

T-Games

This is a tool developed by Mendes and Romão (2011) that allows children to create their own quiz games. While the application itself is not an actual game, it allows children to take up the role of instructor and create their own game. This helps them explore and learn about scholar subjects as they create the questions and solutions of the game. The created game will then help them, or other children, learn about the same subjects by playing it.

Gem-Game

This is an educational math game created by Giannakos et al. (2012) and developed in Scratch[9] with the objective of testing the impact of storytelling in educational games. In this game the main character's dog is kidnapped by a witch and the player must collect thirty diamonds for the witch to give it back. The screen is divided by lines and the player makes the character move up or down by writing a number. If the character is in line 6 and there is a diamond in line 1, the player must write "-5" in order to move the character to the right place. This way, the game requires the player to add or subtract numbers correctly to get to the diamonds.

Roll a Die

This is a mobile educational math game, created by Aranas et al. (2018) and developed in Unity. In this game the player must help a student get to school by correctly answering a series of multiple-choice questions (Figure 2.4). If the player answers a question correctly, the student will move towards the school. The player wins the game if the students reaches the school before the time ends. In the end the player can see their score and average time and decide if they want to play again (Figure 2.5).

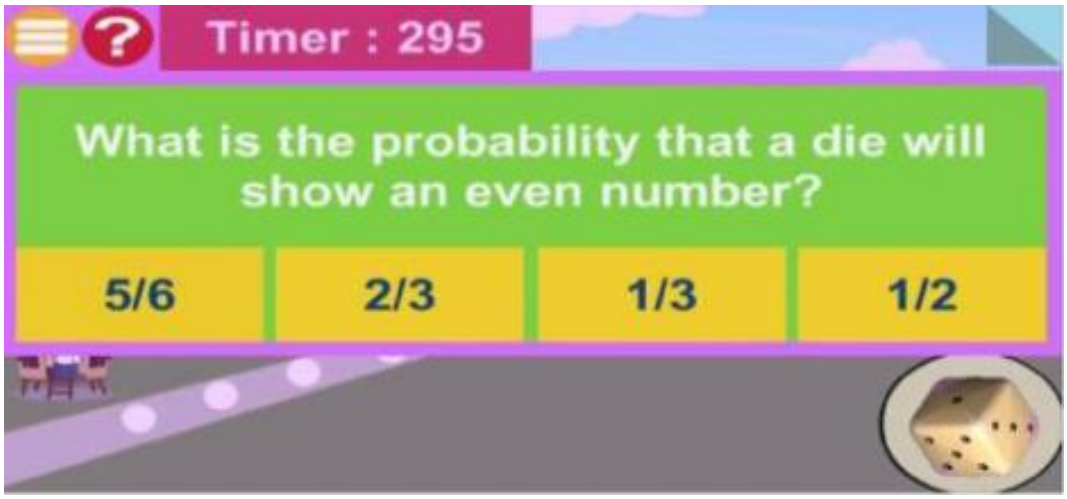

Figure 2.4: Roll a Die – Question Screen

[9] https://scratch.mit.edu/

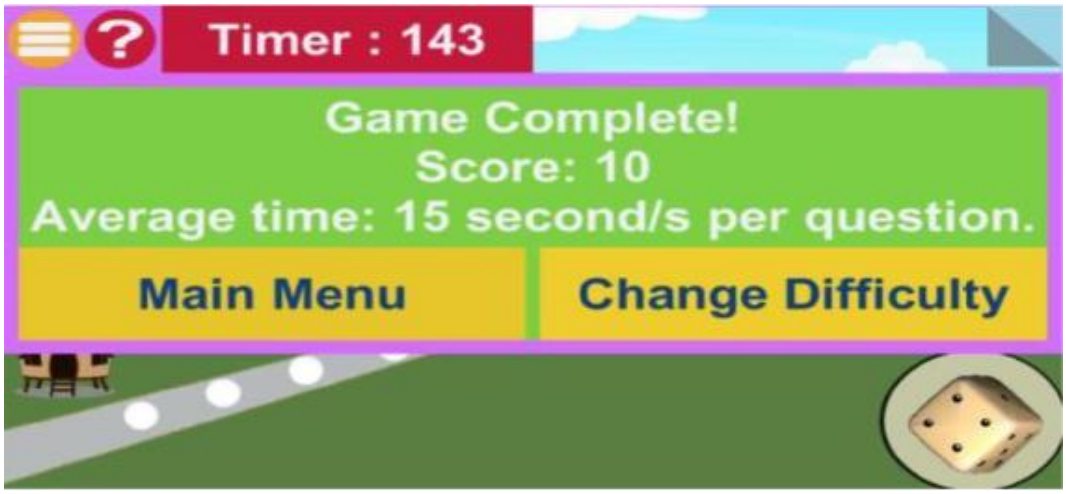

Figure 2.5: Roll a Die – Victory Screen

Apart from these four examples, you will find more games in the next sub-chapter that can be considered educational games (e.g. Scribblenauts, Who Wants to be a Millionaire). The big difference between these games is that the ones mentioned in this sub-chapter were created in an academic environment and focus more on the educational aspects, which means providing knowledge to the player is the central point of the game and it is very obvious to the player that they are learning from playing the game, while the other games are focused more on entertaining the player, and the educational part is more of a "side-effect" of how the game works.

What is different in this dissertation?

The game in this dissertation has common ground with the four examples in this chapter, being a mobile educational game that uses questions as a mean to help children obtain and solidify their math knowledge and also uses storytelling as a tool for motivation. However, this game is innovative in some ways. Firstly, it has the purpose to be played anywhere, unlike What is Geometry, that requires to search for objects in the real world, and T-games, that requires a computer. Secondly, it balances the focus between fun and learning, which Prensky (2001) mentions as the key to success. This makes the educational part of the game less obvious and, as a consequence, more captivating to the children, while still keeping the educational purpose, and is something Roll a Die fails to do, by offering repeated multiple-choice questions, one after the other, through the whole game. And thirdly, it uses new forms of interaction, as the drawing on the screen or tilting the phone to answer a question, which allows the game to not be as monotonous and offer a different way of learning, unlike Gem-Game, that while heavily focused on storytelling, lacks in actual gameplay.

2.2. Game functionalities and games that use them

Videogames can have various functionalities and each one can be applied in different ways. This subchapter contains information about the main functionalities of our game, including the different types of systems, the advantages and disadvantages of each one, and examples of games that already use them.

2.2.1. Question System (Open vs Closed Answer)

When thinking about a question system there are two main types of questions one can think off, open answer and closed answer.

An open answer question should be answered with a statement and gives the person complete freedom over the answer. This type of question allows better understanding of the knowledge of the person answering it, but on the other hand it requires more time and effort on the answer and it is harder to evaluate fairly seeing as different people can answer in different correct ways and with different levels of detail. In games, this type of question is hard to use as it would not only require a very sophisticated system to evaluate the correct and incorrect answers, but also more time and effort from the player, which could lead to a loss of interest.

A closed answer question consists of a question, problem or incomplete statement called the stem and multiple options as answers, being one of them the key (correct answer) and the others the distractors (incorrect answers). ("Multiple Choice", 2018) In games, the player usually has a time limit to choose the correct answer from the options given. Games benefit from using this kind of questions over open answer questions both because they require less time to answer and because they are not open to interpretation. ("Advantages and disadvantages of open and closed questions", 2018)

Example of an open answer question game

Scribblenauts

While games do not usually see the use of open answer questions in a typical way, Scribblenauts uses this system in a special way. Instead of questions or statements, this game presents you with problems that you have to solve by creating objects in the world. You have the power to write anything you want, and that object will then appear in the world for you to use. Creating the right objects is the key to win the game and you have full freedom to solve the problems in any

way you want. Figure 2.6 shows an example of a created object in the game, while Figure 2.7 shows how you create new objects.

Figure 2.6: Scribblenauts – Object Menu

Figure 2.7: Scribblenauts – Object Creation

Example of a closed answer question game

Who wants to be a millionaire[10]

This is a known quiz game that uses multiple-choice questions. You are given a random question and four possible answers. If you choose the right answer, you move on. If you fail the question you lose the game and have to start over. The questions increase difficulty the longer the game lasts. Figure 2.8 shows an example of a question in this game.

Figure 2.8: Who Wants to be a Millionaire –Question Example

2.2.2. Shape Recognition

Shape recognition is a functionality used in various games where the game can recognize a shape (be it drawn or a real-world object, through a camera or a touch screen, or even drawn using a remote or a mouse). The concept is wide, but in this case the relevant situation is the recognition of a drawn shape using a mobile phone's touch screen.

There are two main examples of how this functionality is used. Some games use a tracing method, where the shape to be drawn is shown on the drawing screen and require the player to make a "copy" of that shape, while others allow the player to draw the shape they want without help. The tracing method is useful

[10] https://play.google.com/store/apps/details?id=com.sony.wwtbam2014INT

for when the objective of the game is to teach someone to draw the shapes, as they just copy what is already drawn. The drawing method is more useful in cases where the shape to be drawn is not previously known to the player (for example, if the player has to guess the right shape before drawing it) or if there are various correct options of shapes to draw and the player can choose one of them (for example, in games where you have to cast spells and you are allowed to choose which spell to cast).

Example of a shape tracing game

Paw Patrol Air and Sea Adventures[11]

This mobile educational game for children uses the method of shape tracing by showing on the screen the shape that the player is required to draw and having them move their finger over the shape in order to re-draw it. The game uses the popular paw patrol characters and also teaches other subjects like numbers and counting. Figure 2.9 shows an example of shape tracing in this game.

Figure 2.9: Paw Patrol Air and Sea Adventures – Shape Tracing Example

[11] https://play.google.com/store/apps/details?id=net.pluginmedia.pawpatrolflyer

Example of a shape drawing game

Magic Touch: Wizard for Hire[12]

This mobile game requires you to protect your castle against invaders by casting spells to eliminate them before they get to the ground. Invaders fall down in balloons and drawing the shapes on the balloons will make them pop, killing the invaders. However, you can also use spells in your spell book to execute special actions. You have the freedom to choose which shape or spell to draw and where to draw them and you can draw them in your own way, instead of copying an already drawn shape. Figure 2.10 shows two example screens of this game with different spells being cast.

Figure 2.10: Magic Touch: Wizard for Hire – Example Screens

[12] https://play.google.com/store/apps/details?id=com.nitrome.magictouch

2.2.3. Accelerometer

An accelerometer is a device that measures proper acceleration. In a mobile device, it helps detect motion input (for example, when a user is making movements like tilting or shaking their phone).

The accelerometer became popular in games (even though it had been used before) with the release of the Nintendo Wii console, since the controller came with a three-axis accelerometer designed especially for motion input. Since then, other consoles and mobile games started making use of the accelerometer, including motion input in their games. ("Accelerometer", 2018)

Example of a game using accelerometer

Wii Sports[13]

This was one of the first games released for the Wii, and lets the player use their controller to play different sports (for example, holding a bat on baseball, a ball on bowling or a racket on tennis). It uses the accelerometer included in the remote to detect the movements the player is making and repeat them on the game. Figure 2.11 shows an example of a player playing the baseball mode of this game.

[13] https://www.nintendo.co.uk/Games/Wii/Wii-Sports-283971.html

Figure 2.11: Wii Sports – Accelerometer Example

2.3. Technologies for Mobile/Android games

This chapter mentions technologies for mobile games that are relevant for this dissertation. Since the chosen engine for this dissertation is the Unity engine and technologies differ between engines, some subchapters will be specific to Unity.

2.3.1. Game Engine

There is a big list of options when choosing an engine for a mobile game and each engine has its pros and cons. Here will be mentioned some of the best options at the moment and a small explanation of each of them.

Unity[14]

Unity is one of the most popular engines for indie (independent) game development. It was created by Unity Technologies in 2005 and is now in its sixth version (Unity 2017), having a massive community and support network. While accessing its source code or using extra features and addons may be expensive, those are not usually required.

[14] https://unity3d.com/

Unity supports functionalities like 2D and 3D graphics, drag-and-drop functionality and scripting using C#. For 2D games it provides an advanced 2D world renderer and allows the importation of sprites while for 3D games it allows to specify texture compression, mipmaps and resolution settings for various platforms, and supports various types of mappings (bump mapping, reflection mapping, parallax mapping), dynamic shadows, render-to-texture and full-screen post-processing effects. Unity supports 27 different platforms including Android and iOS. ("Unity", 2018)

Unreal[15]

Unreal Engine is another of the most popular game engines at the moment, developed by Epic Games in 1998. It was primarily developed for first-person shooter games but was since used in other genres like fighting games and MMORPGs. It is currently on its fourth version (Unreal Engine 4) and unlike Unity, does not require you to pay for extra features or addons, taking instead 5% of the royalties on successful games. Like Unity it has a very big community and support network, although not as big.

Unreal supports mostly the same functionalities as Unity, using instead C++ for scripting. The latest version includes a new real-time global illumination algorithm, developer features to reduce iteration time and allow code updates while running and a new "Blueprint" visual scripting system that allows rapid development of game logic without using C++. ("Unreal Engine", 2018)

GameMaker Studio[16]

GameMaker is a simpler game engine used by developers with less experience in creating games. It was developed by Mark Overmars in 1999 and allows the creation of games of different platforms and genres using drag and drop action sequences or its own scripting language (Game Maker Language). It was designed to allow novice programmers to create games without big programming knowledge requirements.

GameMaker mostly uses 2D graphics, allowing only limited use of 3D graphics. Its drag and drop system uses icons that represent actions such as movement or drawing to avoid that the programmer be required to know complex languages like C++ or Java. Programmers can also use the Game Maker Language to create new action libraries if necessary. ("GameMaker Studio", 2018)

[15] https://www.unrealengine.com/

[16] https://www.yoyogames.com/gamemaker/

Chosen Engine

The chosen engine for this dissertation was the Unity engine. From the three main engines mentioned, GameMaker Studio lacks in complexity, while on the other hand Unreal is too complex. Unity has a big community, a big support network, easy access to assets and supports the platforms and features required for this game, which made it the best choice in this case.

2.3.2. Data Persistence in Unity

Data persistence is something required in almost every game. It saves information between game launches, since the programs typically lose all information on shutdown. In unity there are two popular ways to do this.

PlayerPrefs

PlayerPrefs is a class specific to Unity that allows you to save and load persistent data. It is very easy to use, with methods like SetInt and GetInt, and you can save any integer, string or float giving them a key (which you will need to find and load them later) like in a java map. Although it is easy to use, it is also very simple, allowing you to only save integers, strings and floats, meaning that if you want to save more complex data, you will need serialization, as will be mentioned next. (“PlayerPrefs”, 2018)

Serialization

Serialization is the method used when you want to save data that is too complex to save through the PlayerPrefs (like an object with various attributes) and works by converting objects to information in a file. For that, you can use different types of files, like XML, JSON or binary files. This conversion is mostly done automatically, since there are prebuilt serializers to be used in any of the types mentioned. For XML there is the XmlSerializer class (“XML Serialization”, 2018), while for JSON there is the JsonUtility class (“JSON Serialization”, 2018) and for binary there is the BinaryFormatter class (“Binary Serialization, 2018). Even though they are different classes for different types of files, they mostly work in the same way, having a method to serialize (transform from object to file data) and deserialize (transform from file data to object). The choice between the various types of files varies on the needs, with differences on speed and space as shown in Figures 2.12 and 2.13 below. The small data consists of a list with one object while the large data consists of a list with 1610 objects, and the speed values are normalized (showing the speed for each object). (“Serialization performances”, 2018)

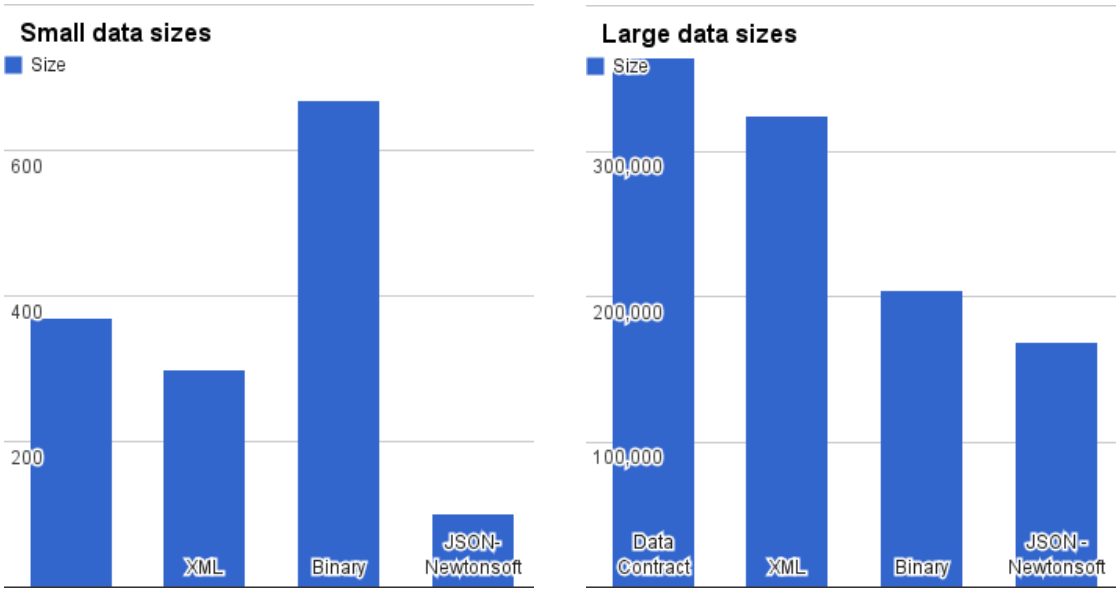

Figure 2.12: Space Comparison Graphics for Serialization in Different Data Formats

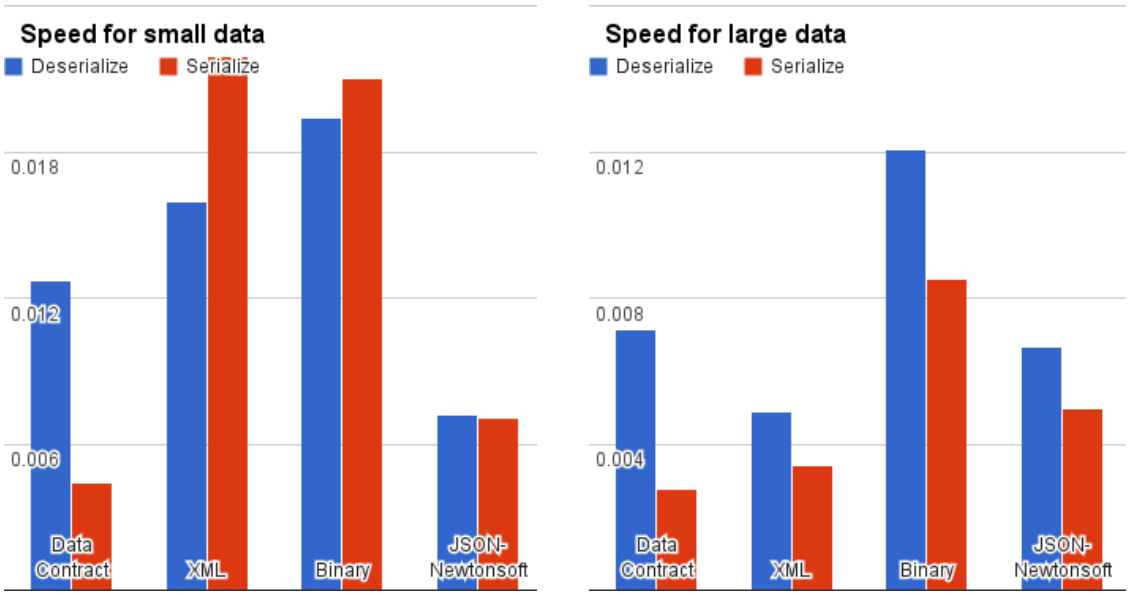

Figure 2.13: Speed Comparison Graphics for Serialization in Different Data Formats

2.3.3. Assets in Unity and Shape Recognition

An asset in Unity is a representation of any item that can be used in your game and can be created outside or within unity. 3D models, audio files and images are all assets created outside of Unity, while Animator Controllers, Audio Mixers and Render Textures are assets created within Unity. (“Asset Workflow”, 2018)

Unity has a huge Asset Store[17], a growing library of free and commercial assets created both by Unity Technologies and by members of the community that has assets ranging from models and textures to whole project examples. While most assets are paid, you can also find free ones that you can use in your project. In this dissertation we used as base (and modified as needed) an asset for the shape recognition part of the game.

[17] https://assetstore.unity.com/

3

A Mathemagical Situation

As mentioned before, our game was created with the purpose of helping students obtain or solidify their math knowledge, with the use of clever techniques to disguise the educational aspect of the game. We do this by having not only different ways of answering questions, but also shifting the focus away from the questions, so that they do not feel like the central part of the game, while adding decision-making and minigames. This helps us have a game that the students will not only enjoy playing but also obtain helpful knowledge from.

3.1. Design Process

3.1.1. Sketching and First Version

At the start of the design process some sketches were made to try out the original ideas and the interface of the game. At that time, this was a fairly different game, with ideas that were eventually changed or cut from the final version.

Mentioning some of the biggest changes:

- **Combat mode:** The game contained rooms with monsters that the player would have to defeat by using various attacks and answering questions (Figures 3.1 and 3.2). While the combat was in a style of Pokémon or Harry Potter (no blood or gore involved), it still introduced violence to our game and due to some negative feedback, we decided to reformulate the game thematic.

- **Linear path:** In this first version the player was not able to choose their own path. There was always only one way he could go (Figure 3.3), having only one available door instead of three, that was always locked. Players would then have to solve educational riddles to unlock the

doors and progress (Figure 3.4). We cut this idea as we wanted to offer more choice to the player and felt like this would be too repetitive and not very enjoyable in a large scale.

- **The theme did not fit:** This version of the game had a darker theme, as a "dungeon crawler" type of game. You would progress through a dungeon, defeating monsters, until you finally defeated the final boss and won the game. We felt this did not fit the math theme and it was a bit too dark for our target audience. In addition to that, it was harder to create a strong narrative that would make sense based on this premise. In the end, we created the current story of the game.

Figure 3.1: Early Sketch – Combat Mode

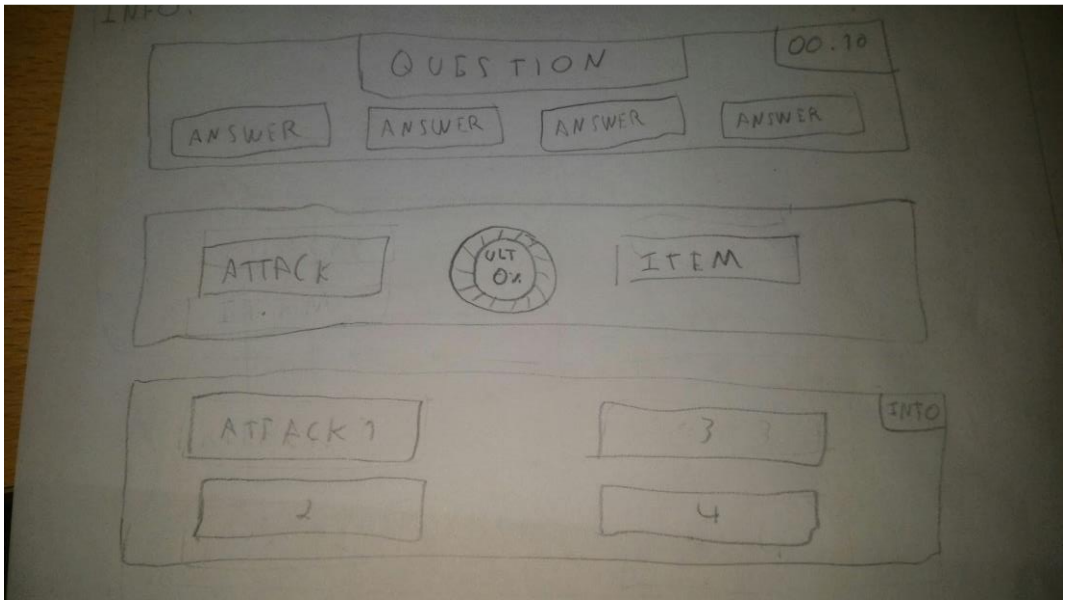

Figure 3.2: Early Sketch – Combat Mode Info Bars

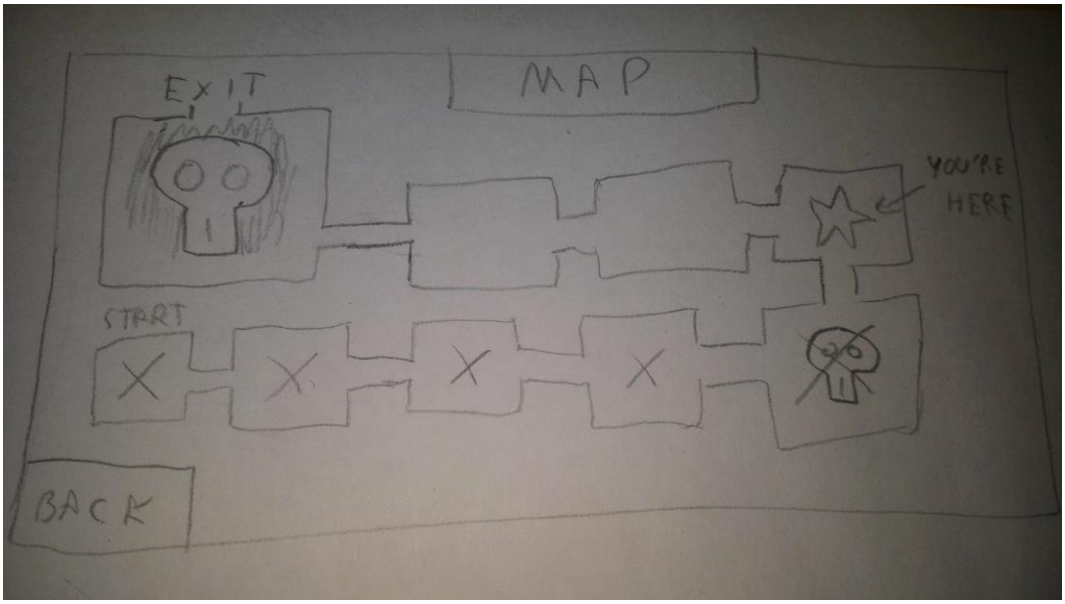

Figure 3.3: Early Sketch – Progression Map

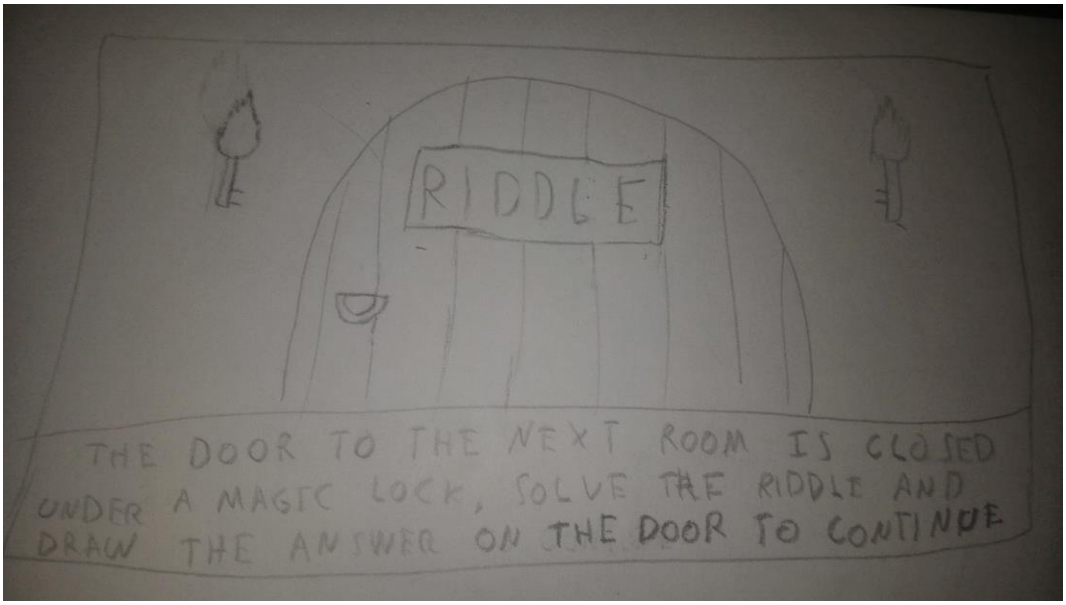

Figure 3.4: Early Sketch – Riddle Screen

3.1.2. Iterative Design Process

To create our game, we followed an iterative design process, as defined by Dix et al. (1998). This involves a cyclic process of designing, implementing and evaluating a product, as shown in Figure 3.5.

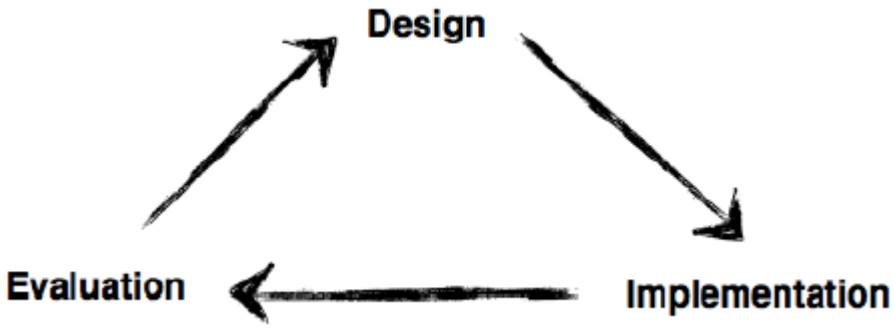

Figure 3.5: Early Sketch – Progression Map

This helps improving the quality and functionality of the product and its interfaces.

Our game, at this point, went through two phases of this process (not considering the early sketches). Our first prototype, containing the basic interfaces and gameplay of the game, was then tested in June. From these first testing sessions we learned what was working and what was not, we got feedback and new

ideas from the testers, and we designed a second prototype that we then implemented and tested again in October. The second testing sessions provided us, once again, with feedback and new ideas for a later version of the game. Eventually we will be able to implement and test them once again, to continue the cycle, until the game is at its maximum potential.

3.1.3. Design Techniques

As mentioned in chapter 2, good videogame design follows some important rules. Especially when designing a game with the purpose of teaching a subject the students usually do not enjoy (as with math in our case), if not handled carefully, the players will easily lose their motivation to play. To avoid this, our game utilizes several techniques:

- **Difficulty Levels**: The game must be challenging to the player but should have a balanced difficulty level (not too easy nor too hard) in order to keep the player interested in playing. Since every person is different, we created several difficulty levels in the game so that everyone can find the right difficulty for them. This way, once they beat a certain difficulty level, they will also have a harder challenge to beat that will keep them playing the game.

- **Use of different skills**: This game requires math knowledge to beat, obviously, but that is not the only skill it requires. Requiring different skills from the player at different times makes the game less repetitive and more enjoyable. If a player finds a chest and has to decide if they want to risk losing a life for a chance to get an artefact, or if they have to decide when they should use an artefact or keep it for later, they're using strategic thinking. If a player has limited time to answer a question (as in the drawing questions) or catch a required number of potions (as in the minigame), they are using their capacity to act under pressure. These skills are also important for other aspects of the player's life.

- **Strong narrative**: A game where the player does not know or understand why they are doing what they are doing does not keep them motivated. This game uses a strong narrative, in way of a backstory, several dialogue bubbles throughout the game, and character interactions, so that the player feels connected to the story and does not get confused. Using a story about magic, with a defined villain, and letting the player feel like the hero of the story, also helps motivate them to play.

- **Sense of progress and accomplishment**: Another big aspect of a game is its capacity of transmitting to the player that their actions matter. Every time you get a key, you are closer to finding the wizard. Every time you win a minigame, you are rewarded with an artefact. Every time you answer correctly to a question, you save one of your lives. This way, the player feels good by completing the game's objectives, and that helps to keep them playing.

- **Various forms of interaction:** Sooner or later in an educational game the player will be faced with a test of their knowledge. This is essential, as it is what allow the players to learn from the game. But there are ways to make it more entertaining than just answering a question using a keyboard or clicking a button. Our game uses different forms of interaction to make the questions less boring to the player. In one question they may have to draw the answer, while on the other they may have to move their phone in a certain way. This way, the game makes even the educational part more entertaining and less repetitive.

- **Minigames:** It is good to have a break once in a while, and minigames offer that. In our game, players will sometimes be faced with a minigame they can choose to play or skip. They are risk free (there is no punishment for losing, only a reward for winning), and they are games made purely for fun (there is no educational purpose). They exist so that the players do not get overwhelmed with questions and feel tired, while also offering them a special reward once in a while. They are a "feel good" situation.

3.2. Game Description

The game consists in walking through the corridors and rooms of the magic mansion in search for the evil wizard, choosing which doors to enter, and facing the challenges that lie within each room, while trying to obtain the keys needed to unlock the final room. The game ends when the player finds the final room and defeats (or is defeated) by the evil wizard in a math duel. A game will usually last around 10 to 15 minutes.

3.2.1. Difficulty/Mode Options

When starting a game, the players will come upon several screens with options. The first one (Figure 3.6) will let them choose their school year (currently fifth or sixth grade), so that the questions inside the game are tailored to their current

knowledge. Fifth graders will get only questions from fifth grade, while sixth graders will get questions from both years (so that they can also practice what they learned before).

The second one (Figure 3.7) will let them choose the difficulty level of the game, from the four difficulties available. The three usual difficulties (easy, medium and hard) do not change the core of the game but make it easier or harder by altering the number of lives you start the game with and the chance of the evil wizard answering questions correctly (this will be explained later). The fourth difficulty however, called survival, does change how the game works. In this mode the player will start with one life and not be able to obtain more. This means as soon as they fail a question, the game is over. This is a harder challenge for the players who beat the hard difficulty and want to try something even more challenging.

The third and final choice screen (Figure 3.8) will let players choose which character they want to help. Currently they can choose between a boy or a girl, and this does not affect the game mechanically, simply using the chosen character throughout the story. More characters can be easily added in the future.

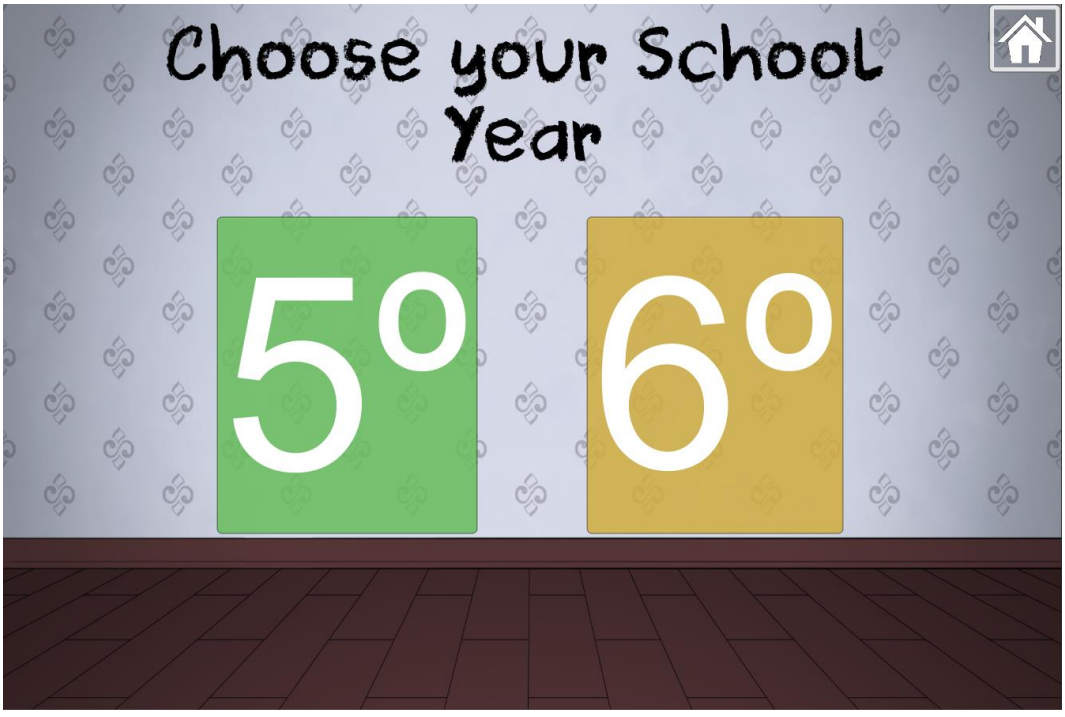

Figure 3.6: School Year Choice Screen

Figure 3.7: Difficulty Choice Screen

Figure 3.8: Character Choice Screen

3.2.2. The Corridors

After the option screens and a small introduction to the story, the player will find themselves in a corridor with three different doors (Figure 3.9). This will happen throughout the game, every time the player leaves a room. Each door in the corridor leads to a different room, and the player has to choose one of them. After clicking on one of the doors the player will be taken to a room.

Figure 3.9: Example Corridor

3.2.3. The Rooms

There are several types of rooms in the mansion, each one requiring the player to execute different actions.

Key Room

This is the kind of room the player will want to find, as it contains a key, essential to finding the wizard (Figure 3.10). The room in which the wizard is hidden is protected by magical wards, and the player will not be able to find it until they obtain seven keys. When in this room, the player simply needs to click the key to obtain it and then click the door to exit back to a corridor.

Figure 3.10: Key Room

Question Room

In this room the player will find themselves trapped, with the exit being locked with a magic spell. To continue, they will have to answer a math question (portrayed as if they were casting a spell from the character's spell book). If they fail to answer the question correctly, they will lose one of their lives.

There are four different types of questions:

- **Multiple-choice** (Figure 3.11): This is the simple question method most people know. A question with four different predefined answers, and the player must choose the correct one. In this type of question, the player has all the time they want to choose their answer, but they only have one chance.

- **Drawing** (Figure 3.12): This question has no predefined answers, instead having only a square in which the player can draw their answer. The answer is always a simple character (such as a one-digit number). In this type of question, the player can try to guess the answer as many times as they want in the period of thirty seconds and lose if they fail to find the correct answer in that time.

- **Tilting** (Figure 3.13): This question leads the character to a frozen room with two different keys, one on each side of the room. Each key corresponds to an answer to the question asked, and the player should tilt the phone to make the character slide towards the correct key. Once the character touches a key, it is shown if that was the correct answer. This type of question is used exclusively less than/greater than questions and applies to whole, decimal, negative numbers and fractions.

- **Clock** (Figure 3.14): This question shows the player a clock and asks that they move one of the pointers in order to make a specific angle between the two pointers. The player can control one of the pointers by tilting their phone, while the other pointer will be frozen in a random place and will not be moveable. When the player thinks the angle is correct, they can submit their answer by clicking the button. The game offers an error margin and considers angles inside that margin as correct. Currently, this type of question is used exclusively for the subject of angles.

Figure 3.11: Example Multiple-Choice Question

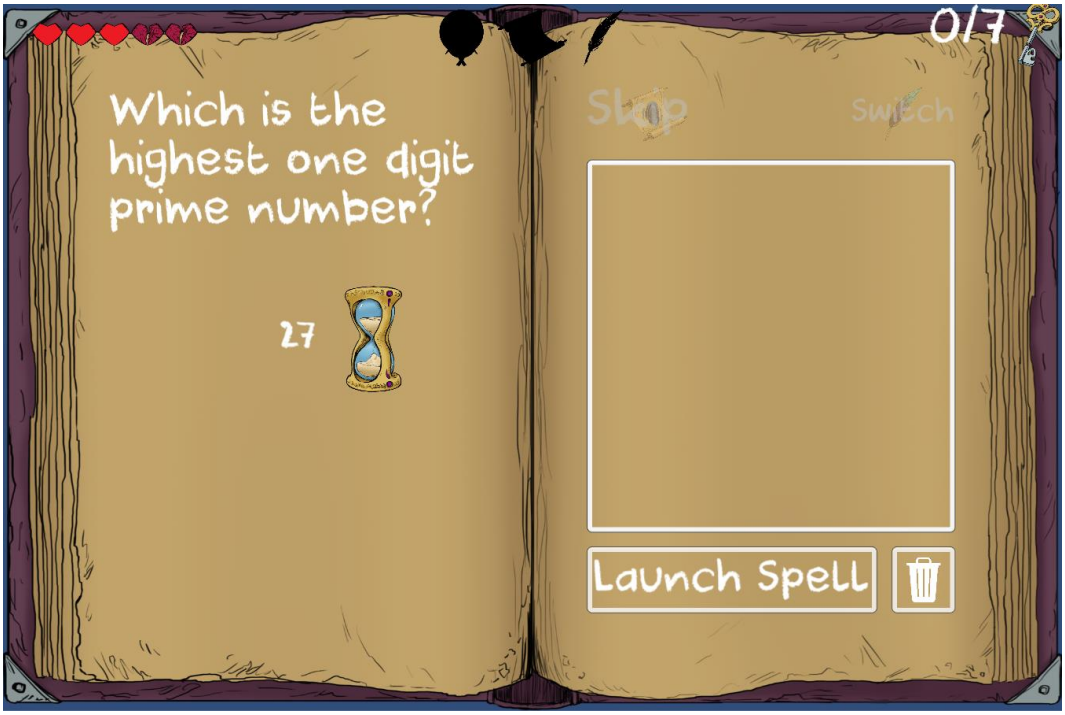

Figure 3.12: Example Drawing Question

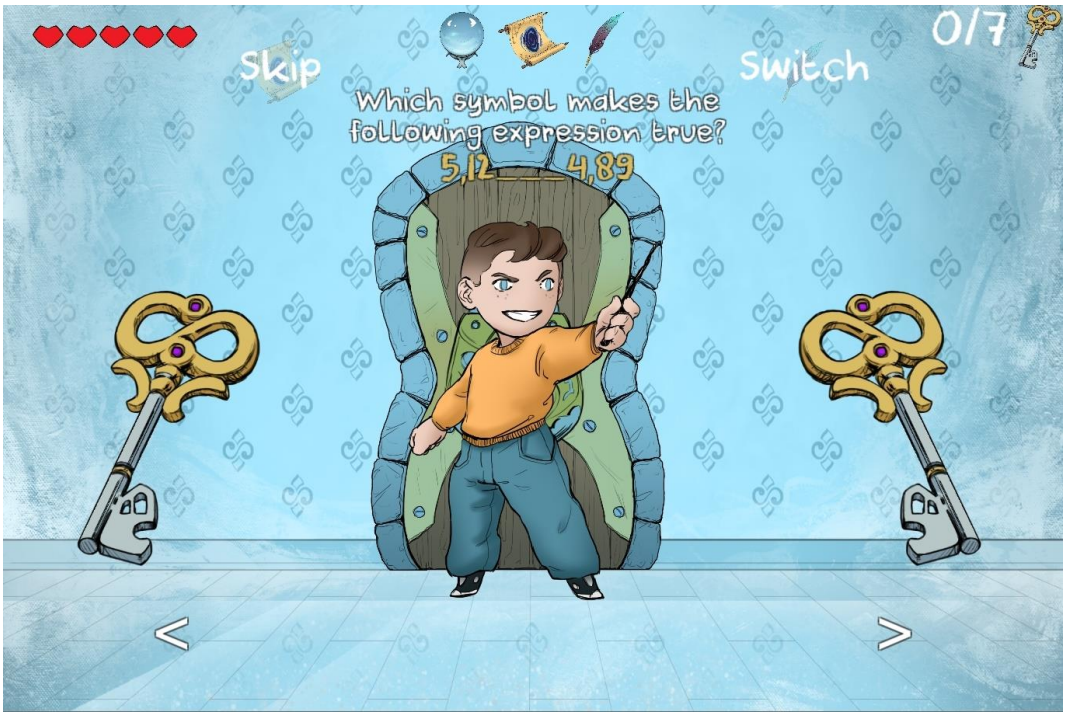

Figure 3.13: Example Tilting Question

Figure 3.14: Example Clock Question

After answering, the player will be shown the correct answer, a brief explanation, and proceed to a room that will then lead back to another corridor. In case they failed the question, they will also lose a life.

Treasure Room

In this room the player will find a chest that they can decide to open or not. The chest contains one of the following treasures:

- **Crystal Ball**: When faced with a multiple-choice question, this can be used to remove two of the wrong answers.
- **Portal Scroll**: When faced with any kind of question, this can be used to skip it.
- **Feather Pen**: When faced with any kind of question, this can be used to change it to a new question.
- **Life Medallion**: Grants the player an extra life.
- **Cursed Medallion**: Takes a life from the player.

With the risk of losing a life, the player should plan well when to open a chest. The player can only carry one of each artefact and will keep it until used.

Minigame Room

In this last type of room, which is especially rare, the player will have the chance to play a minigame (Figure 3.15). Completing the minigame requirements will award the player with their choice of treasure (Figure 3.16). At this time the only available minigame requires the player to lean their phone in order to help the character move and catch the potions falling from the sky. Catching fifteen potions in thirty seconds will complete the challenge. In case the player is not interested in the minigame, they can also use a button to simply skip it and move to the next room.

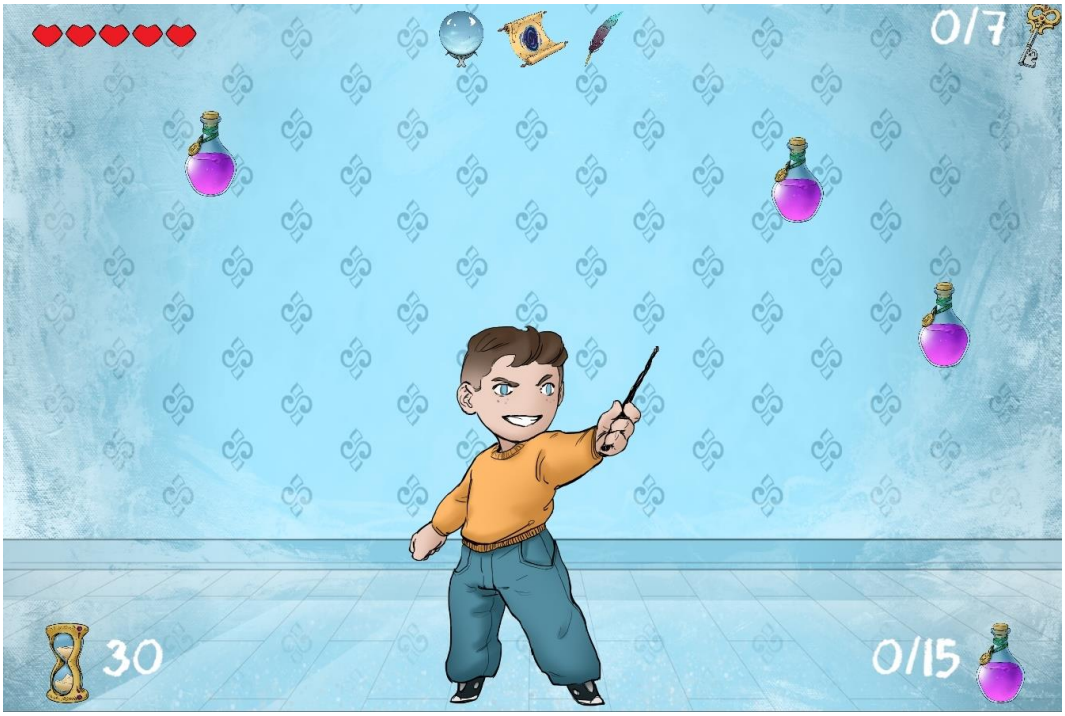

Figure 3.15: Minigame Room

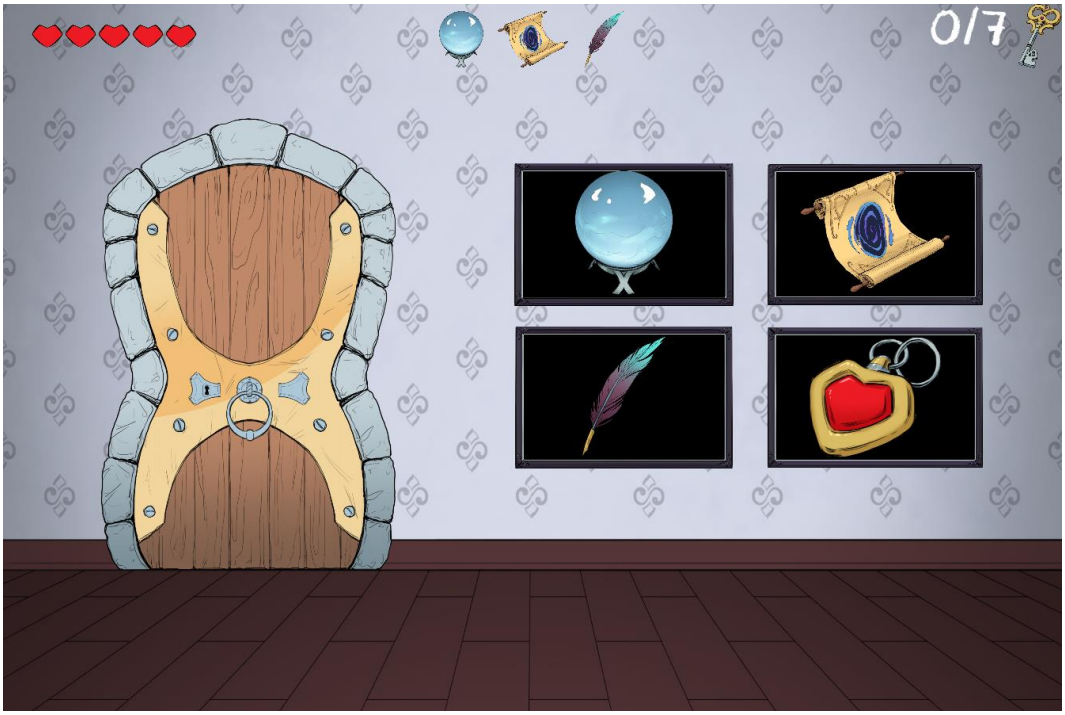

Figure 3.16: Treasure Choice Room

3.2.4. The Final Duel

After obtaining seven keys, the player will instead find themselves in a corridor with just one door, different than all the others (Figure 3.17). This door leads to the evil wizard's private room (Figure 3.18), where the final duel for the fate of all mathematic will happen. Once in the room, the player and the evil wizard will both have to answer a series of multiple-choice questions. The player will start with the lives he saved throughout the game, while the evil wizard (being evil and a cheater) will start with full (five) lives. Every time the player answers a question, the evil wizard will answer it too, at the same time (using a simple algorithm), and each wrong answer makes them lose a life. If the player manages to survive until the evil wizard loses all their lives, they win the game (Figure 3.19). If both the player and the wizard lose their last life at the same time, it will be a draw. The evil wizard will become more or less intelligent depending on the difficulty level chosen at the beginning of the game (with a chance of choosing the right answer around 50% in easy, 67.5% in medium and 75% in hard).

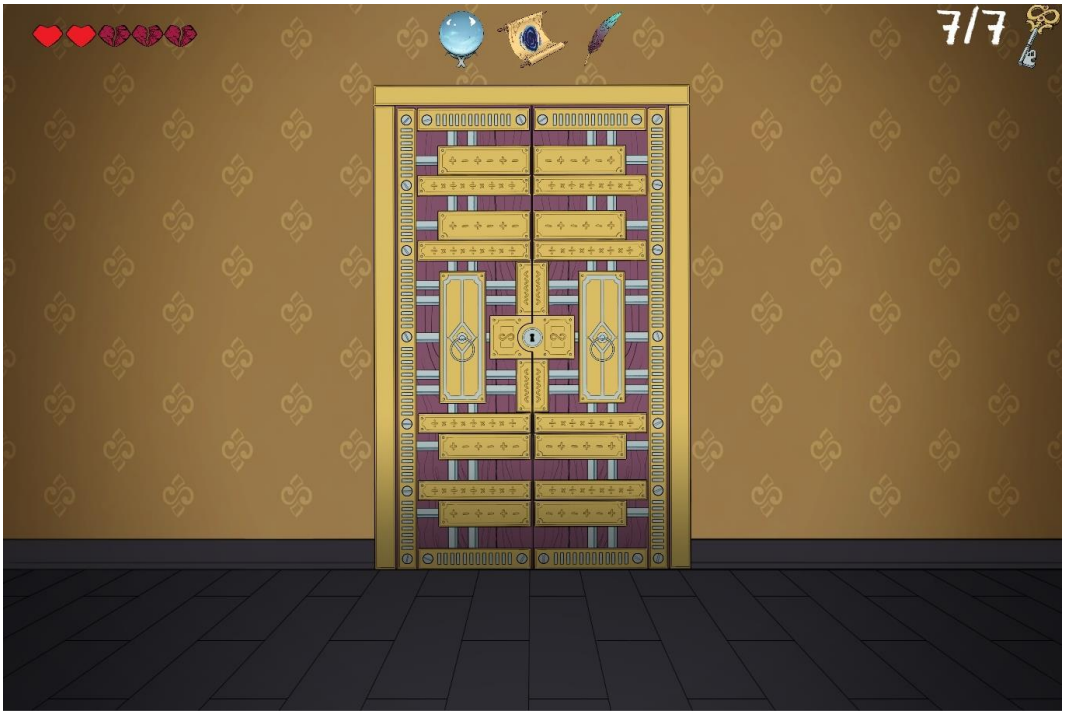

Figure 3.17: Final Door

Figure 3.18: Final Duel

Figure 3.19: Victory Screen

3.2.5. Interface

The interface of a game must be able to transmit all the necessary information to the player so that they can understand and play the game. Our game uses a fairly simple interface with elements that help the player understand the game and their progress (seen in Figures 3.9 through 3.18). During most of the game the player will have represented on their screen three important visuals:

- **Lives**: Depicted on the top-left corner of the game screen, the player can easily see the number of lives they have (represented by a heart) and the maximum amount of lives they can have (up to five, represented by a broken heart).

- **Artefacts**: Located at the top-center of the game screen, the player can see which artefacts they currently possess (appearing coloured) and the ones they do not (appearing as a black shadow).

- **Keys**: Located on the top-right corner of the game screen, the player can see how many keys they have, and the total number of keys required. This will be replaced by the evil wizard's lives once the player gets to the final duel.

All the buttons on the game screen are also fairly explicit so that the player knows exactly what they do.

3.3. Implementation

This sub-chapter presents the technologies we decided to use in the implementation of this game and briefly refer how we used each of them.

3.3.1. Unity

Unity was the game engine chosen to create this game. Unity games are comprised of a series of scenes with several game objects and C# scripts that execute actions. In this game each screen is a different scene and, due to the nature of the game, most game objects are UI objects as canvas, buttons and images. Scripts are then executed to change the UI depending on the actions of the player, creating the interactivity of the game.

3.3.2. PDollar Point-Cloud Gesture Recognizer

PDollar[18] is the shape recognition asset used for the developed game. This asset works by letting the developer add (by drawing) any shape they want and save it with a name. The information is then saved in an xml file as a series of points. When the player then draws a shape and submits it, a script runs through every file, finds the closest one to that shape and returns its name. As it works this way and there are many ways of drawing the same character, the detection was "calibrated" by asking the children in the first testing sessions to draw several characters on paper which were (manually) added to the files of the asset.

This script was modified to fit the game as in this case we need it to compare the name returned with the right answer to the question.

Additionally, as some shapes can be very similar and create problems with the algorithm of this script, which works by finding (using a greedy search) the saved file whose points have the least distance to the points drawn, it was modified to also accept as a correct answer any shape that is very similar to the one required, in the case it detects a different (similar) character as the best match.

[18] https://assetstore.unity.com/packages/tools/input-management/pdollar-point-cloud-gesture-recognizer-21660

3.3.3. JSON Serialization

This game uses two JSON files, one to load the questions from and one to store and load the player information. The player information file contains information as the current state of the game, arrays of unanswered questions, and data like current lives, keys and artefacts, chosen character, difficulty and year, and what was the last screen the player was in. This all allows the player to close the game when they want to without losing their progress. When the app is paused or closed the information is automatically saved to the file and when the app is loaded again it will check for that file and load the information so that the player can continue where they left off.

3.3.4. Accelerometer

Smartphones come with an accelerometer, a sensor that detects movement. If a phone is held parallel to the ground, the value of the acceleration is 0. Tilting the phone to the right or left will return a positive or negative acceleration value, respectively, that will increase the more you tilt it. Using this acceleration value, we were able to create screens where the player can effectively control the character, making them slide to one side or another depending on how the player tilts their phone.

3.3.5. Auto-generated Questions vs Manual Input

There are two ways to create questions for a game. We can either create them manually or let them be automatically generated by code. Both approaches have their strong and weak points, and both are used in our game.

When the questions are created manually, it is easier to create more creative and unique questions, and it is easier to give a more precise justification regarding the correct answer. As we are trying to improve players' knowledge, it is important that the students understand exactly how things work. The downside to these questions, however, is that they require a human to keep creating and manually adding them to the game, and eventually the player will have answered them all unless there is a constant stream of new questions being added. We decided to use manual questions in the multiple-choice and drawing modes as they are the ones where we can fit the most variety of questions and used them as a more general approach. This is what should help the students obtain and maintain their knowledge bases, as there are questions focusing on every math subject with detailed justifications.

Automatically generated questions, on the other hand, have the benefit of being generated by code and not requiring a human to keep adding them to the game. As they are generated randomly, the number of different questions that can be generated is huge, so realistically a player will never answer them all. The downside to these questions is that they mostly follow a mold, and the justifications are more generalized, as it is hard to automatically generate a specific justification for the answer to each question. These questions are better utilized to focus on a specific subject, when the player already has the bases and does not require as much explanation to their errors but wants to further train their knowledge. We use these questions in the tilting and clock modes, and we intend to add more types of questions in the future (focusing on each one of the subjects).

This is how the automatically generated questions work in the current modes:

- **Tilting:** For this mode, we first generate a random number to choose one of the categories available (whole numbers, decimals, fractions and, in the sixth grade, negative numbers). Then, we generate two random different numbers in an acceptable range for the chosen category and use them to create the question (i.e. 1st number ___ 2nd number) that the player must complete with the right symbol (i.e. > or <).

- **Clock:** In this case, we generate a random (whole) angle X, between 5 and 180 and use it to create the question (i.e. Create an angle of X using the pointers of the clock). We chose 180 as the upper limit as these are the most commonly used angles in the target scholar years. Then we generate a second random angle, this time from 0 to 360, and use it to rotate the fixed pointer of the clock into a random position.

4

Evaluation

To test our game and study its effectiveness on the students, we had two testing sessions, each one with two different sixth grade classes in a school. The first one happened in June with a more simplistic prototype of the game, while the second one happened in October with a more final prototype. In these sessions we not only evaluated the educational effectiveness of the game through a math test, but also gave the students a small questionnaire followed by an informal conversation with them, so we could know their opinion of the game and where it needed to be improved. Bear in mind that the first session happened at the end of a school year while the second session happened at the start of a school year, which creates differences in the knowledge of the students.

The user tests occurred in a classroom and lasted around 1h30m for each class (including the math test, gameplay and the questionnaire) and the respective post-sessions (one week after, for a second math test) lasted around 20 minutes. On both user studies the following methodology was used:

- First, we asked the students to do a math test, so that we could have an idea of their math knowledge before playing the game. We gave them around 20 minutes to do this test.

- Next, we instructed them to install the game and start playing. The participants were asked to install the application on their phone or tablet through google play (with explicit authorization from a parent or legal guardian). Then, we gave them a brief explanation of the game's story and premise beforehand but did not teach them how to play, in order

to test the interface's usability. We let them play the game for around 50 minutes.

- In the end, we offered them a questionnaire to fill and had an informal conversation with them. This lasted around 20 minutes.

- One week after, we met again in the classroom and asked them to repeat the math test they had done the previous week, to check if the game had improved their knowledge. Bear in mind that we did not offer them the solutions to the test, nor did we inform them beforehand they would be repeating the same test, to avoid them finding the answers. This, as the first math test, lasted around 20 minutes.

During the test session, team members observed the students, assisted with any problems they faced and had informal conversation with them after they answered the questionnaire.

The test and questionnaire were strictly individual, but during the gameplay part the participants were allowed to join and help their friends, and during the informal conversation they were allowed to share their opinion on others' ideas.

4.1. First Prototype

The first session took place in June, we tested a total of 29 students from two classes. Class A consisted of 10 students (6 boys and 4 girls) and class B consisting of 19 students (11 boys and 8 girls) of the sixth grade, with ages between 10 and 11.

This first prototype was a more basic version of the game (version 1.0.1). Comparing to the current version, there are several differences that could affect gameplay:

- **No Difficulties:** In this earlier prototype, there was only one default difficulty, that acted as the current medium difficulty.

- **Bad Detection:** As the asset of shape detection works based on the shapes we give it beforehand, it was not properly calibrated to the various types of calligraphy that the students would use, often causing it to assume right answers as wrong or vice versa.

- **Bad Interface:** The interface at the time was found to be confusing to the players in some aspects. You can see the changes we made post-session in 4.2.

- **No Tilting/Clock Questions:** In this first prototype, these did not exist. The only types of questions available were multiple-choice and drawing, making the game more repetitive and boring at the time.

- **Less Amount of Questions:** At the time, it was planned for a teacher to create the questions for the game. However, close to the date of the session, the teacher who had accepted to do the questions failed to comply, which forced us to create the questions ourselves with little time to spare. Because of these, there was a smaller amount of questions available than we hoped for, which made the players quickly start answering repeated questions.

- **No Minigames:** Minigames were an idea that emerged from the feedback of the first session, so they did not exist at this time.

4.1.1. Educational Effectiveness

To find out if the game was actually doing its purpose of helping students learn and retain math knowledge, we had to test their knowledge before and after playing the game. The way we did this was to give them a simple math test with 16 open answer questions. This test contained questions present in the game and covering various subjects, although adapted for an open answer and with different values. We gave them this test before introducing them to the game, then let them play the game for a week, and then repeated the same test to check if there were improvements.

Before playing the game:

- Class A had an average score of 38%, with the lowest score being 13% and the highest being 63%.

- Class B had an average score of 30%, with the lowest score being 0% and the highest being 63%.

After playing the game:

- Class A had an average score of 40%, with the lowest score being 6% and the highest being 69%.

- Class B had an average score of 45%, with the lowest score being 6% and the highest being 75%.

From comparing the tests, we could observe the following results:

- Both classes improved after playing the game, with Class A increasing its average score by 2% and its highest score by 6%, and Class B increasing its average score by 15% and its highest score by 12%.
- In Class A, three students increased they score, while five maintained it and two lowered it.
- In Class B, seventeen students increased they score, while one maintained it and one lowered it.
- The student that improved the most in Class A went from 38% to 56%, a 18% improvement. In Class B, the student that improved the most went from 0% to 44%, a huge 44% improvement from just one week of playing.

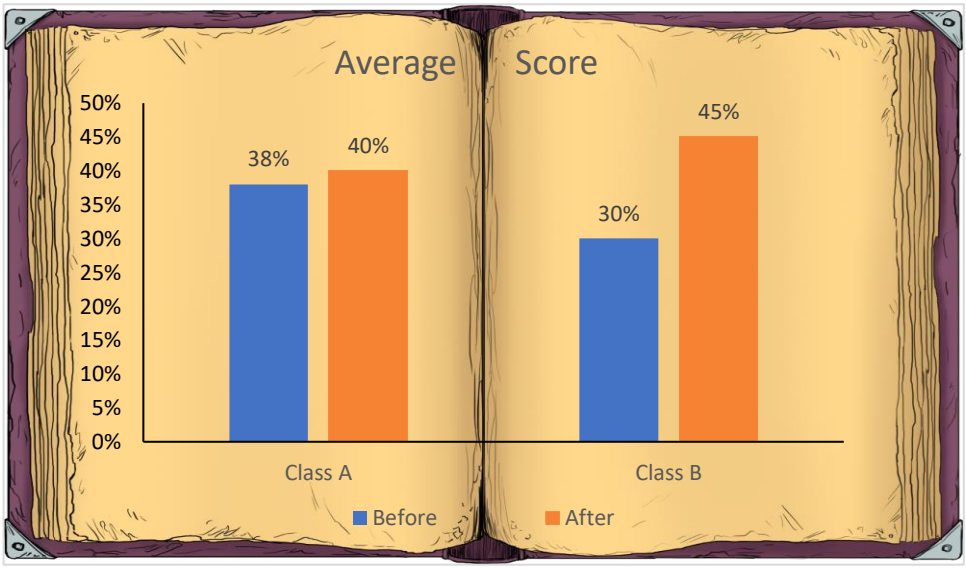

Figure 4.1: First Session – Average Score

4.1.2. Questionnaire and Feedback

The questionnaire we gave the students after they experienced the game had six questions. The first question asked them to indicate in what devices they usually studied or played. The four following questions asked them to rate aspects of the game in a five-point scale. For these questions we used a technique named Smileyometer, developed by Read (2008) as part of the Fun Toolkit. While this was not entirely needed, as the students at this age are capable of reading and understanding the scales, it still helps transmit the information through emotions so that it is more easily understood. The last question just asked for their opinion on what to add or improve in the game.

Here you can see the results of the questionnaire. In Figures 4.1, 4.2, and 4.3, there were 32 answers. In Figures 4.4 and 4.5 there were 31 answers, as one of the students did not answer those questions.

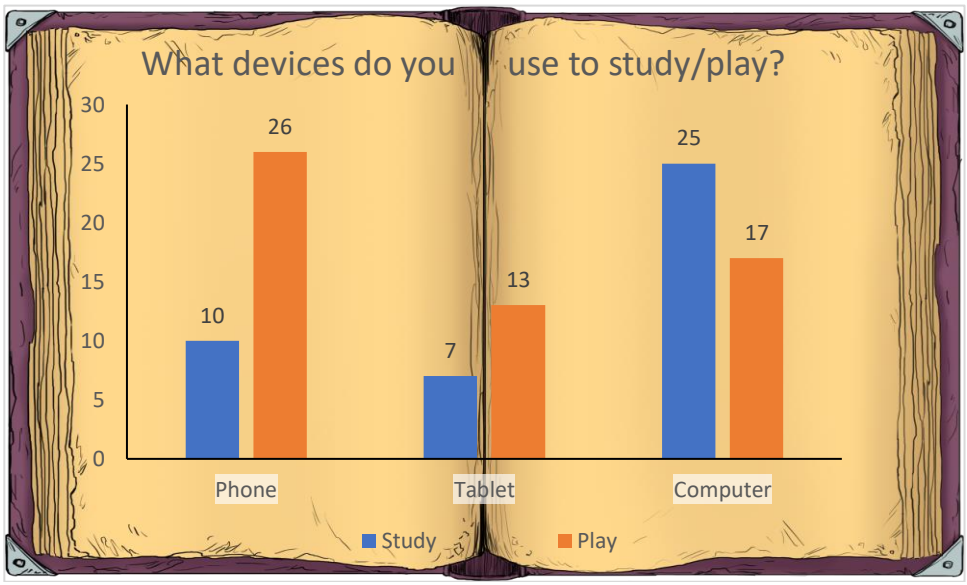

Figure 4.2: First Session Questionnaire Results – Question 1

In Figure 4.2 we can see most of the students use their phone to play (26 out of 32), while using mostly their computer to study (25 out of 32). This supports our decision of creating a mobile educational game, as it provides a way for kids to study while playing, and in any place. This is also the best platform for the game as they are already used to playing on their phone and will most likely play the game there than if it was on a computer.

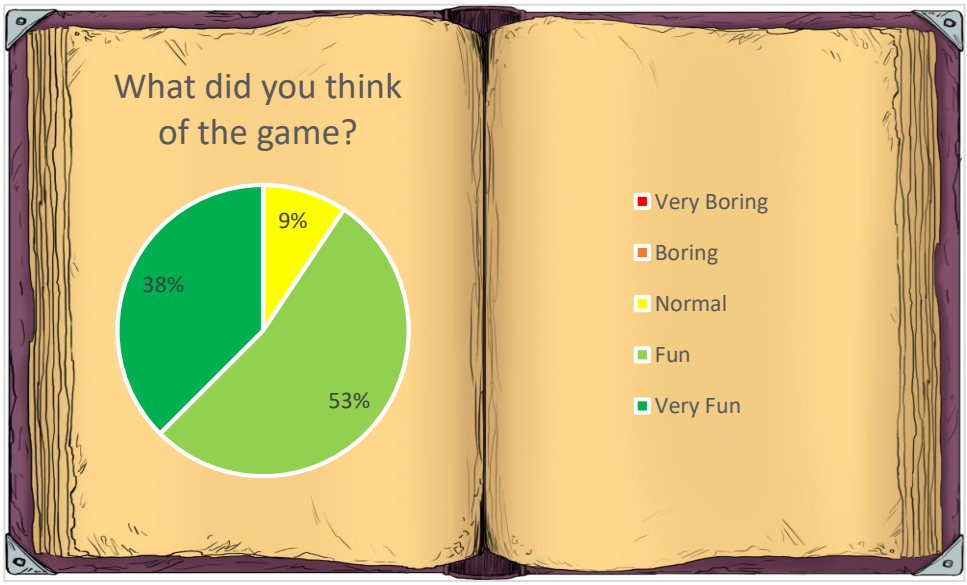

Figure 4.3: First Session Questionnaire Results – Question 2

In Figure 4.3 we can see most of the students enjoyed the game. While most students rated the game as fun, the positive feedback corresponds to 91%, while the other 9% are neutral, which means the game was well received.

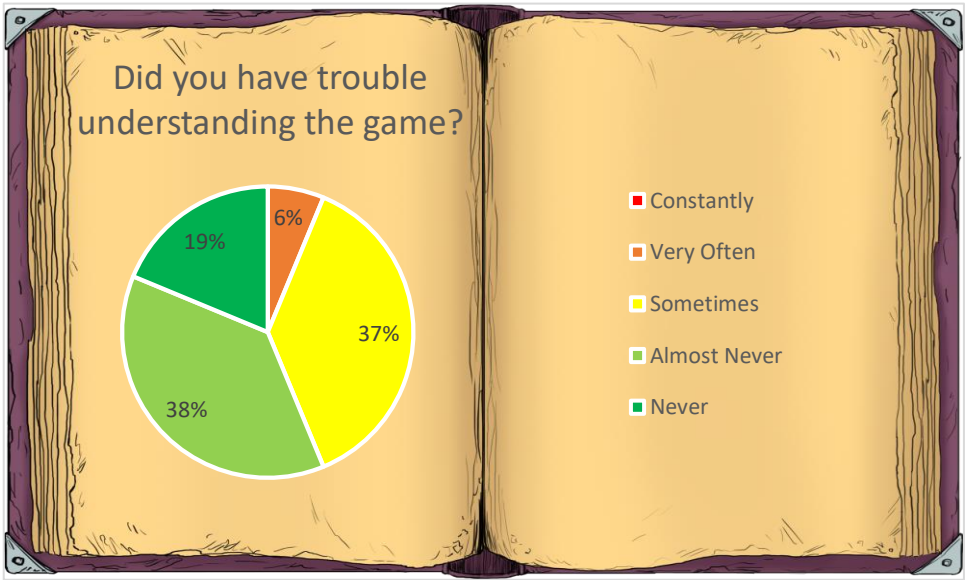

Figure 4.4: First Session Questionnaire Results – Question 3

In Figure 4.4 we can notice some students had trouble understanding the game. The ideal here is for a student to never have any trouble understanding the game, however, as people tend to skip crucial information (in the way of dialogue bubbles), it is understandable that some students may end up confused sometimes. While more than half (57%) of the students almost never had trouble understanding the game, this was an aspect that still required improvement. According to the feedback gathered during this test session, various changes were made to the UI of the game to make it easier to understand, as described in 4.2.

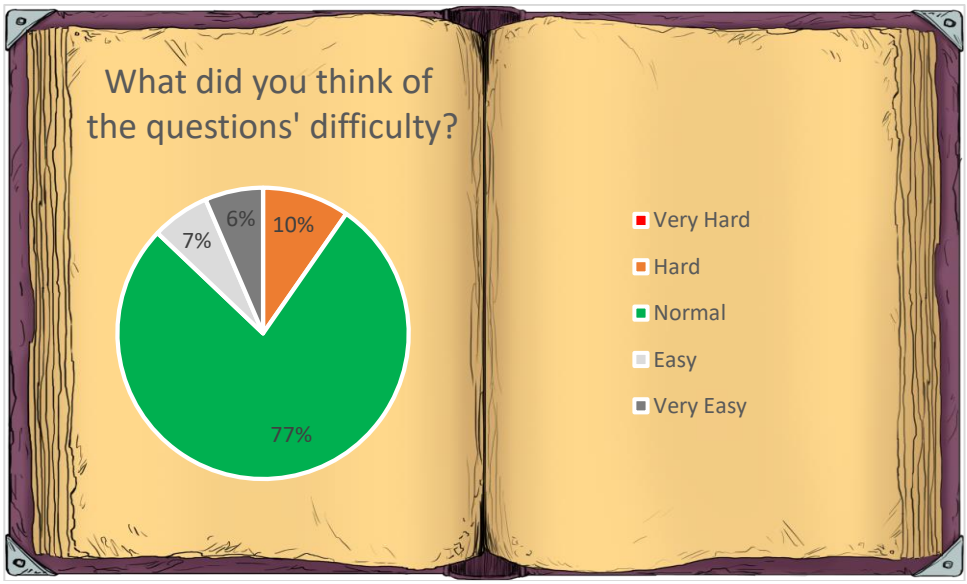

Figure 4.5: First Session Questionnaire Results – Question 4

In Figure 4.5 can be found the students' opinion on the difficulty of the game's questions. The objective here is for the questions (generally) to be neither too hard nor too easy, and that seems to have been achieved, with 77% of the students finding them to be "normal". While the other 23% found them to be either too easy or too hard, as there are questions of various difficulties and students of various skill levels, it is not surprising that this happens and can hardly be avoided.

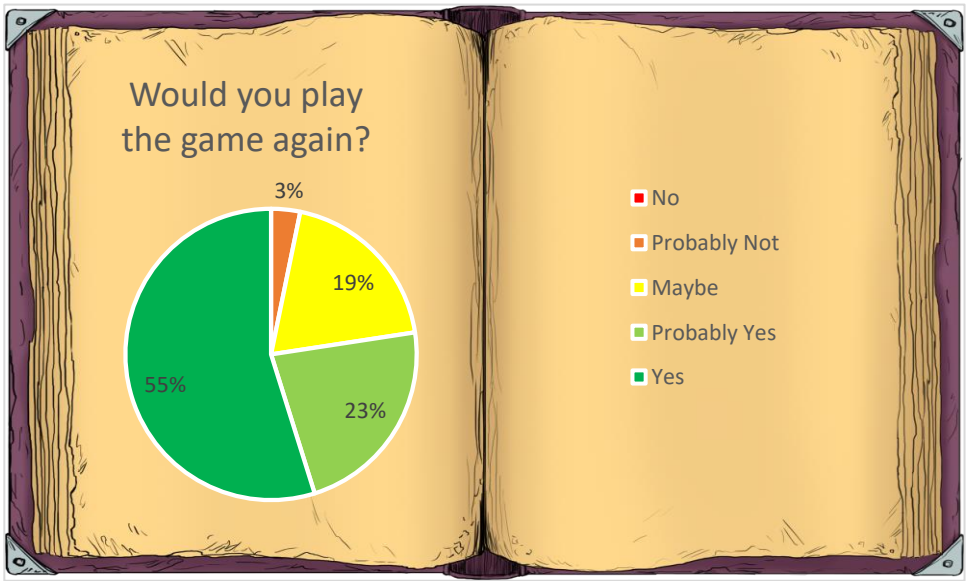

Figure 4.6: First Session Questionnaire Results – Question 5

In Figure 4.6 we can see more than half of the students (55%) would definitely play the game again, while 23% would probably play it. This, again, is mostly positive feedback, seeing as the majority of the players liked and would continue to play our game. As the game was at an early stage during this evaluation, we expected the results to improve on the second evaluation.

Player Feedback

The students were very helpful and enthusiastically provided a lot of interesting feedback during this evaluation. Most of them gave good ideas to expand the game in the future, with more levels, characters, themes, a co-op or versus mode, a shop to buy artefacts or even a more powerful version of the evil wizard that could change the game. Some of the ideas given were actually implemented in the game, like various difficulties and minigames and some we even intend to implement in the future, as being able to focus on a specific math subject at a time and having more characters to defeat and unlock.

In addition to giving us ideas to improve the game in a ludic sense, they also helped test and inform us of what was not working or needed improvement on a technic side. For example, at the time of testing, the detection asset still could only detect a few ways of drawing each character. However, most kids drew the characters in different ways, which resulted in the game sometimes assuming they had failed even when they drew the right answer. Other times, the game would freeze or have an unexpected behaviour. With this feedback, we could see what was failing and improve/fix it.

During the session we also observed the students playing and talked to them personally, which gave us other type of feedback like being able to notice, for example, when a player was confused about some aspect of the game, if they were enjoying it, if they were getting frustrated, if they missed important information or misunderstood the purpose of a button.

We also observed that the students would, by themselves, create situations of collaboration or competition, by trying to help friends or trying to beat the evil wizard before they do, and they seemed to have fun playing the game during the whole session. The students were also enthusiastic and eager to help during the informal conversation we had after they finished the questionnaires.

All these forms of feedback allowed us to improve the game to hopefully make it more enjoyable to the players in the future.

4.2. Post-session Interface Changes

During the first testing session we noted the players were having trouble with some parts of our interface, and used that information to make our interface more understandable:

- **Click to Collect Item**: In the Key room, the player is required to click the key to collect it. However, when opening a chest in the treasure room, the same could not be done, since in that case a player could open the chest and then decide whether to pick up the item or not (and no one would pick up the cursed medallion). But since the interfaces acted in different ways, the players usually would try clicking on the treasure to collect it, and nothing would happen, creating some confusion. This was solved by making the treasure disappear from the screen (even though the player collects it as soon as they open the chest and do not really need to click it).

- **Undo Button**: During development a button was added to the drawing question screen, which would let the player undo the drawing and start again, in case of a mistake. However, instead of the current icon (a trash can), the button had the usual undo icon (an arrow in a circle going backwards). This created some confusion with the users, that would click that button not realizing it was deleting the drawing. This was solved by changing it to the current icon.

- **Dialogue Bubbles**: When the dialogue bubbles were added, every time one was shown, the player had to click on the screen to make it disappear before making any other action. Actions like clicking on a door, or a chest, or a key, were deactivated while the dialogue bubbles were active. However, we realized that players would usually try to execute those actions while the bubbles were active, creating confusion when the expected result would not occur. We solved this by making it so that when the active dialogue bubble is the last one of that screen (meaning that it will not be replaced by another one), all other actions can be executed and will both remove the bubble and execute the action in the same click.

- **Using Artefacts:** When a user obtains an artefact, a dialogue bubble pops up explaining what that artefact can be used for. However, most users just skip dialogue bubbles, and that creates problems. In early development, on the question screens, the artefacts were represented by buttons with their respective uses (50/50, Switch and Skip). However, there was no direct connection in the interface between these words and the artefacts, making the players wonder what they were used for. Later we added, behind each

button, a semi-transparent image of the corresponding artefact, so that the user understands that using that help will consume the respective artefact.

4.3. Second Prototype

This second prototype (version 1.3.4) already contained all the features mentioned in 3.2, only differing from the current version of the game in some minor changes and bug corrections.

In the second session, in October, we tested a total of 30 students, with class C consisting of 16 students (5 boys and 11 girls) and class D consisting of 14 students (6 boys and 8 girls) of the sixth grade, also with ages between 10 and 11. None of the students had participated in the previous user study, nor previously tried the developed game.

4.3.1. Educational Effectiveness

As in 4.1.1, to test this second prototype we also gave the students a simple math test, this time containing 14 open answer questions. Again, this test contained questions present in the game and covering various subjects, although adapted for an open answer and with different values. This time, however, the test only covered fifth-grade subjects, as the students had just begun sixth grade and did not have the knowledge required to answer the sixth-grade questions yet.

As before, we tested their knowledge before they played the game, and then again, a week after, with the same test, to see the improvements.

Before playing the game:

- Class C had an average score of 51%, with the lowest score being 14% and the highest being 71%.
- Class D had an average score of 37%, with the lowest score being 7% and the highest being 86%.

After playing the game:

- Class C had an average score of 67%, with the lowest score being 21% and the highest being 93%.
- Class D had an average score of 43%, with the lowest score being 7% and the highest being 86%.

From comparing the tests, we could observe the following results:

- Both classes improved after playing the game, with Class C increasing its average score by 16% and its highest score by 22%, and Class D increasing its average score by 6%, although the highest score did not improve.
- In Class C, thirteen students increased they score, while three maintained it. No one lowered their score.
- In Class D, five students increased they score, while seven maintained it and two lowered it.
- The student that improved the most in Class C went from 50% to 86%, a 36% improvement over the course of one week. In Class D, the student that improved the most went from 14% to 50%, also a 36% improvement.
- While both classes had a different rate of improvement, most students still improved after only one week of playing the game.

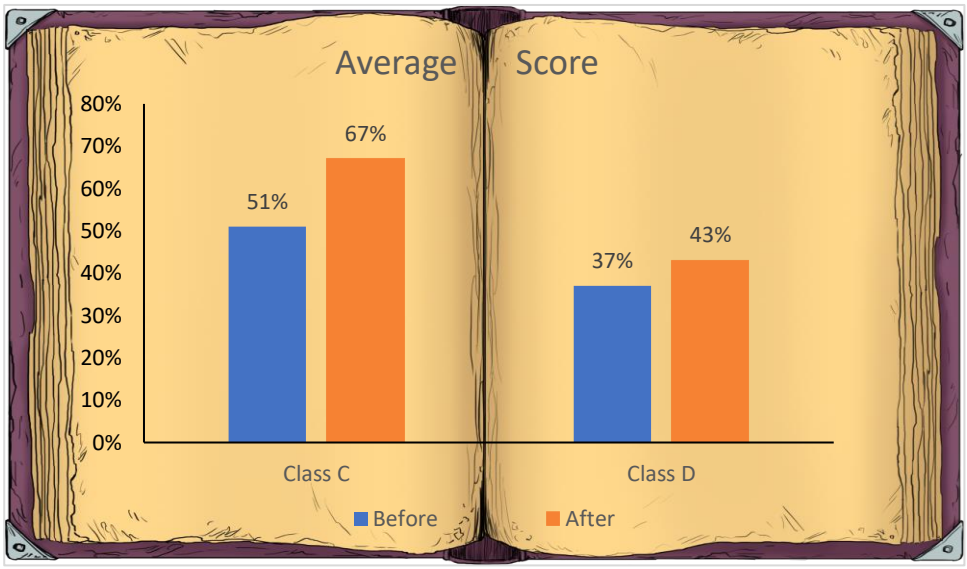

Figure 4.7: Second Session – Average Score

4.3.2. Questionnaire and Feedback

Here you can see the results of the questionnaire. This questionnaire, although similar to the one of the first session, had one extra question that asked the students to rate various parts of the game from best to worst. Although there were more students, the study was made based on only 25 answers, as the rest of them either did not answer or answered in a way that could not be properly considered.

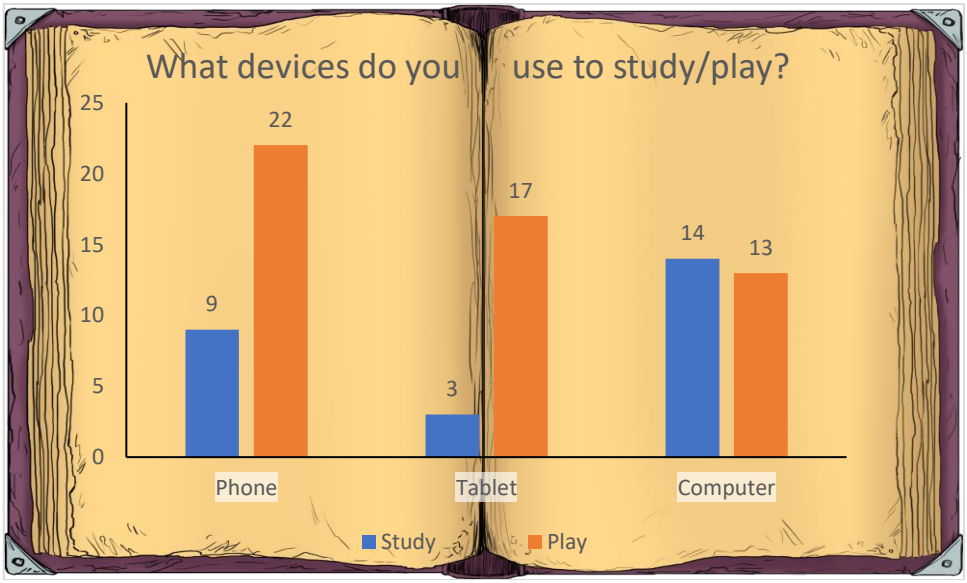

Figure 4.8: Second Session Questionnaire Results – Question 1

In Figure 4.8 we can see that, as in the first session, most of the students use their phone to play (22 out of 25). In this case they use both the computer and the phone to study, but the computer is still the device they use most to study (14 out of 25). There was also an increase in number of students that use a tablet to play (17 out of 25). This continues supporting our decision of creating a mobile educational game for the same reasons mentioned in the previous session.

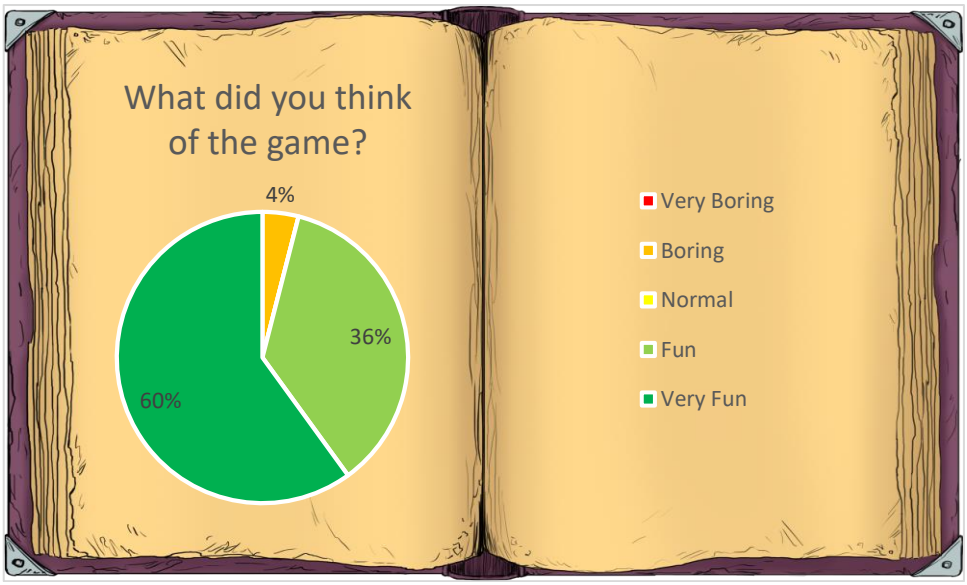

Figure 4.9: Second Session Questionnaire Results – Question 2

In Figure 4.9 we can see most of the students enjoyed the game. The positive feedback corresponds to 96%, while the other 4% are neutral, which means the game continues to be well received.

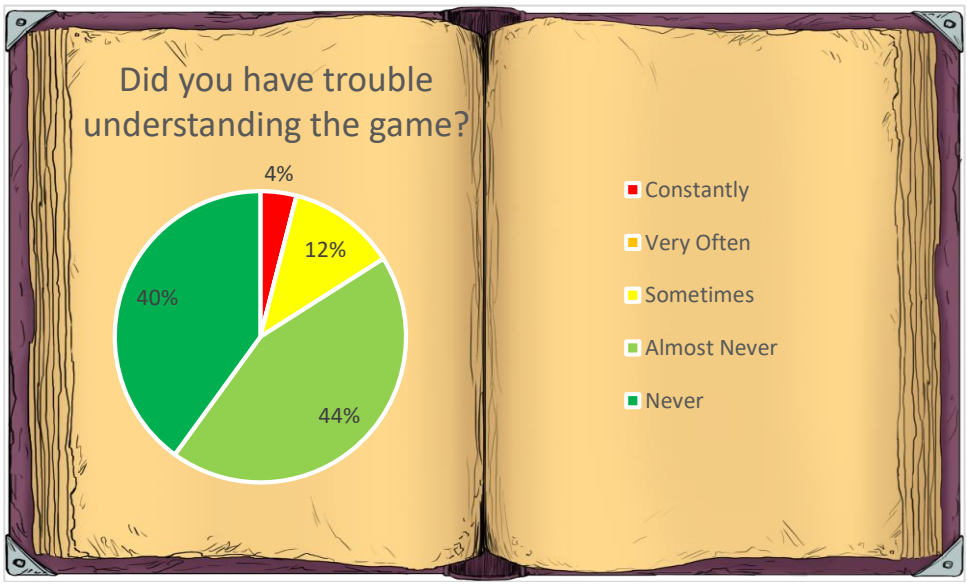

Figure 4.10: Second Session Questionnaire Results – Question 3

In Figure 4.10 we can notice some students still had trouble understanding the game. The ideal here, as mentioned before, is for a student to never have any trouble understanding the game, however, as people tend to skip crucial information (in the way of dialogue bubbles), it is understandable that some students may end up confused sometimes.

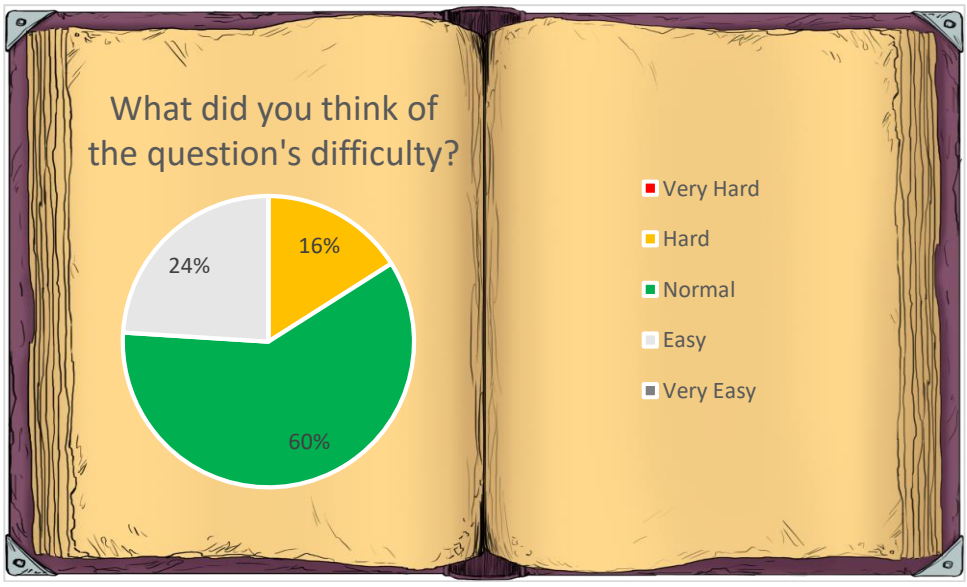

Figure 4.11: Second Session Questionnaire Results – Question 4

In Figure 4.11 can be found the students' opinion on the difficulty of the game's questions. The objective here is for the questions (generally) to be neither too hard nor too easy, and that seems to still have been achieved, with 60% of the students finding them to be "normal". While the other 40% found them to be either too easy or too hard, as we have mentioned before, there are questions of various difficulties and students of various skill levels, which makes it hard to avoid.

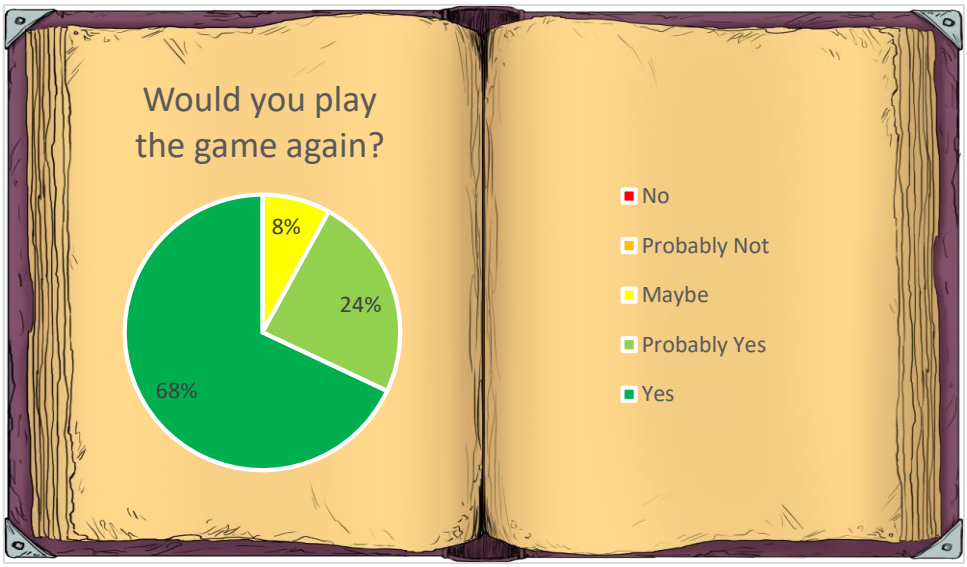

Figure 4.12: Second Session Questionnaire Results – Question 5

In Figure 4.12 we can see more than half of the students (68%) would definitely play the game again while 24% would probably play it. This, again, is mostly positive feedback, seeing as the majority of the players liked and would continue to play our game.

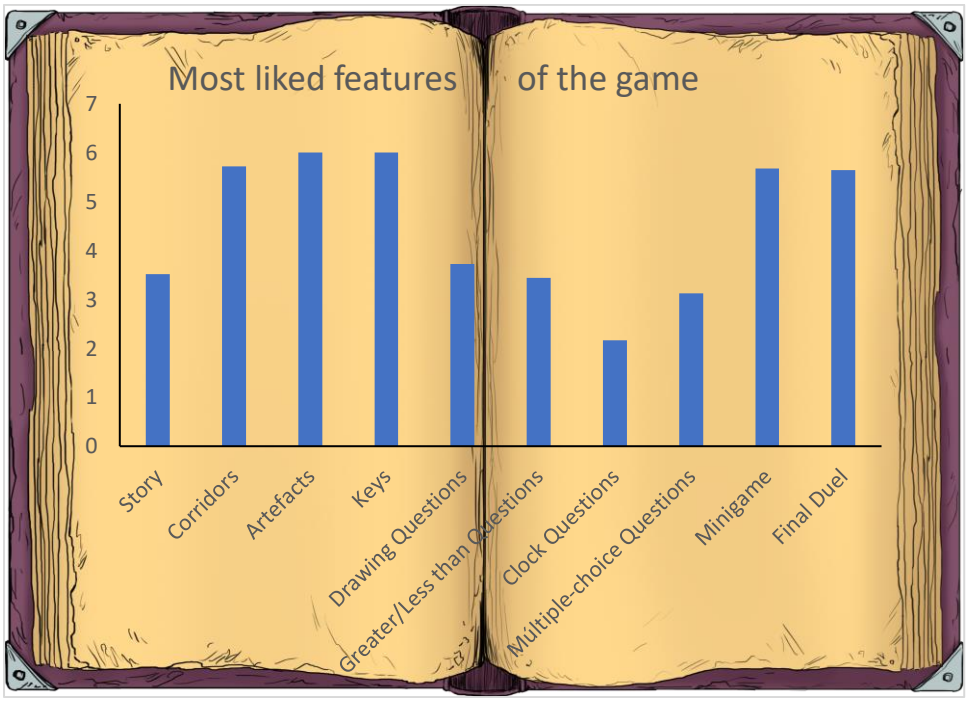

Figure 4.13: Second Session Questionnaire Results – Question 6

Lastly, in Figure 4.13, we asked the students to sort (from 1 to 10) the parts of the game they liked the most and the least. Checking the graph, which shows the average of the scores, we can see what needs a bigger improvement (mostly due to being less forgiving and a bit confusing, things we already fixed) are the clock questions. In the same way, students seem to enjoy more the game itself than the questions, which was to be expected, with the clock questions being the less appreciated and the drawing questions being the most liked type of question. However, they seem to enjoy the final duel to the level of the rest of the game, which is surprising, seeing as the duel involves many questions as well. Overall different students like different things and the game as a whole seems to be working well for them.

Player Feedback

The students were again very helpful with feedback during this evaluation. While not giving as much feedback for new features to add to the game, there were still some good ideas, especially for more minigames and ways of playing.

We also noticed that most feedback focused on the frustration of playing one of the questions, the clock questions, where you have to make an angle with the pointers of a clock. Players seemed frustrated as they could not make the right angles and sometimes did not understand there was a margin where the game accepts the answer as correct. We already made improvements, increasing the

margin in easier difficulties (currently being 15 degrees above or below in easy, 10 in medium and 5 in hard) and are currently working on how to make the error margin more perceivable. Hopefully this will remove the player frustration.

As with the first session, we also observed the students playing and talked to them personally, which gave us other type of feedback like being able to notice, for example, when a player was confused about some aspect of the game, if they were enjoying it, if they were getting frustrated, if they missed important information or misunderstood the purpose of a button.

Again, as in the first test session, the students created by themselves situations of collaboration or competition, trying to beat the evil wizard before their friends, and coming together to defeat the game in harder difficulties.

The new additions to the game since the first session, apart from the problems with the clock questions mentioned above, were well received in general.

All these forms of feedback allowed us to, once again, improve the game to hopefully make it more enjoyable to the players in the future.

4.4. Comparing the Results

If we compare the result from the two testing sessions, we can see the feedback was always mostly positive throughout the development, but we can see some slight changes from the first to the second session:

- We can see a huge increase in players finding the game very fun (from 38% to 60%), which means the improvements made to the game went in the right direction.
- The percentage of players that had trouble more than a few times (which is the concerning part) went down from 43% to just 16%, and the percentage of players that never had trouble (which is the ideal) went up from 19% to 40%. With these results we can conclude the improvements to the UI made after the first session were helpful to the players.
- While there was an increase (from 23% to 40%) on the percentage of players that found the game's questions to be either easy or hard, in the second session no one found the questions to be very easy. This,

however, is hard to control, as there will always be questions of different difficulties and players of various skill levels playing the game.

- In the second session we got a 13% increase on the number of players that would definitely play the game again, while the number of neutral players went down from 19% to 8% and no one said they would not want to play again. Overall, the players found the game to be more interesting and enjoyable.

Overall, the second session's results mostly improved on the already good results of the first session, meaning our prototype improved between these two sessions.

4.4. Guidelines for Future Educational Games

One of our goals in this dissertation was to study and create guidelines for future games. From our study (through both scientific articles and interaction with the children) we found several factors that help on the success of an educational game:

- Being story-driven. The learning aspects of the game should be connected to the story and feel like a consequence of playing the game instead of a main objective. However, be careful that the story and the learning aspect must fit together, not feel like they are two separate parts of the game.

- Having various goals. As soon as the player completes all the goals the game has to offer, they will lose the motivation to play. Different difficulties, different levels or even achievements or new characters to unlock all help keep the player interested in the game.

- Having most (if not all) of the factors that promote intrinsic motivation. These are challenge, curiosity, control, fantasy, competition, cooperation and recognition. Some of these are connected to what was said before, as the story is included in the fantasy and the goals are included in the challenge, but when creating a game, it is always good to check if these factors are present.

- Being easy to understand. The players must be able to easily understand most, if not all of the game, without external help. Specially if the game is focused on younger children, as they will most likely not pay attention to any text or explanation given.

- Being diverse. If the game is too repetitive, players will get tired easily. Whenever you can, just change something up. Levels with different looks or different game phases, various forms of interaction, unexpected turnarounds in the story or even ways to customize your character or make decisions in the story.

These guidelines are not a magic formula to create a good game, it all depends in the way they are used. However, following them should give you a good start in the right direction.

5

Final Considerations and Future Work

Nowadays we are in the era of technology. Constantly, new technologies are created, new applications for existing technologies are found, and people are already used to having it as a mean for almost everything.

In this era, students start having contact with technology from a very young age, and when they join middle school most of them already has a smartphone of their own.

While technology can be very helpful, it can also be distracting and have a negative impact on the students' academic performance. Since technology is already so intertwined in people's lives, what needs to be done is focusing on ways of using it so it has a positive impact on people.

To fix the problem of students (in this case, from fifth and sixth grade) getting behind and losing important knowledge bases (specially in math), that exists since ever, we decided to use a technology that the students mostly use for playing on their free time (the smartphone) and create a game that would let them feel like they were still playing and enjoying their free time, while also helping them obtain (if missed) or solidify the knowledge they obtain at school.

Using tools like storytelling and different forms of interaction, and shifting the focus away from the educational factor of the game by adding decision making situations and minigames, we managed to create a game that is both enjoyable and useful.

A prototype of the game was also tested with sixth grade students, so that a study could be made in the actual effects of the game and the reaction of the students to it.

5.1. Final Considerations

From the testing sessions with the students we managed to obtain some valuable information:

- Generally, the students had a low score in our math test, which means they have difficulty understanding the subject. Choosing math as the subject to tackle was then a good option, as there is lots of room for improvement.

- Most students use their phone as the "go-to" platform to play games but not many of them use it to study. This means that choosing the phone as a platform for our game was a good choice, since not only it will have more adherence from the students (as it is where they usually play), as it will also give them a new platform to study.

- The students seemed to enjoy the game. Not only did they enjoy being challenged by the game, but they also enjoying teaming up or being challenged by their friends, to see who could beat the game the fastest. This means we were going in the right direction, as the core of the game was enjoyable and challenging and the kids did not seem to be demotivated by the math questions.

- At the time of our first testing session, the biggest problem was understanding how the target players think and act. Some of them had difficulty understanding the game, due to them having a different thought process or just being too eager to play and skipping the dialogues, which gave them important information. That testing session helped us understand more about them and make changes to the game to solve most of those issues. On the second testing session there were less issues, the students were more interested and having more fun as the game was in a better state and we could test the game more properly and think of small changes that would be beneficial to the game.

The results of both testing session were mostly positive, which confirmed we were on the right track. Although improvements can always be made, the goal of helping the students learn doing something they enjoyed was met successfully, since they enjoyed the game and most of them improved their test scores (even if slightly) after playing the game for just one week.

5.2. Future Work

This game was made in a way that allows for it to easily expand in several ways:

- More levels, adding other villains, of a more powerful version of the wizard, for even harder challenges.
- More minigames, adding variety to the game to help the player stay engaged.
- Other forms of interaction, allowing the player to answer questions in more different and creative ways.
- Adding different types of questions focusing on different subjects and a mode that allows players to focus on a specific subject they find difficult.
- Expanding to other school years, creating slightly different versions for kids of different ages, with questions relevant to them.
- Expanding to any other school subjects, changing the game and the story slightly to fit the theme.
- Co-op and Versus modes, passing the already existing enjoyment of teaming up or challenging each other to inside the game.
- Adding an option that allows a student to see their progress on different subjects (if they are getting more questions right on a regular basis).

All of these will improve the game, in one way or another, and hopefully increase its effectiveness in solving the problem this dissertation tries to fix. However, further tests are also required to better evaluate the educational efficacy of the game.

In the case of expanding the game to other school years and subjects, it would allow for a deeper study of the effects of the game, as we would be able to study a broader audience and the influence of other factors (e.g. age) on the results.

6

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